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Progress Report for

A RESEARCH PROGRAM TO REDUCE INTERIOR NOISE IN GENERAL AVIATION AIRPLANES

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INVESTIGATION OF THE CHARACTERISTICS OF AN ACOUSTIC PANEL TEST FACILITY

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Summary

Characteristics of the Test Facility, as used by the Noise Research Team of the University of Kansas, have been investigated. Purpose of these investigations was to determine the effects on the sound pressure level in the Test Facility, caused by varying 1) microphone positions, 2) Equalizer Setting and 3) Panel Clamping Forces. Measurements have been done using a "Beranek Tube" or this Beranek Tube in combinations with an "Extension Tube" and a "Special Test Section." (This Special Test Section was designed to be used for Sound Transmission Tests with an angle of incidence between sound and panel other than 90°.) In all configurations tests have been executed with and without a Test Panel installed.

Finally, the influence of the Speaker Back Panel and the Back Panel of the Beranek Tube on the sound pressure levels inside the Test Tube have been investigated.

The tests are presented and the results are discussed. It is shown that the definition of "Noise Reduction" is more useful in relation to this Test Facility than "Transmission Loss."

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Symbols and Abbreviations

Symbols:		Dimension:
c	speed of sound	ft/sec
f	frequency	Hz
f_n	ormal frequency	Hz
l_x	idth of the enclosure in X-direction	ft
l_y	eight of the enclosure in Y-direction	ft
l_z	length of the enclosure in Z-direction	ft
n_x, n_y, n_z	oblique modes of vibration in X-, Y-, Z- direction, in which the component waves are oblique to all three pairs of the walls	
λ	wave length	ft

Abbreviations:		
AC	alternate current	
FRL	Flight Research Laboratory	
Hz	Herz, cycles per second	1/s
IAS	indicated air speed	
KU	University of Kansas	
RPM	Rotations per minute	1/min
dB	decibel	

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Introduction

In this report tests have been done with an Acoustic Panel Test Facility, as used by the KU-FRL noise research team, for:

1. Various microphone positions, in longitudinal direction as well as in the vertical plane.
2. Different test configurations, using Extension Tube, $30^{\circ}/40^{\circ}$ Test Section and Beranek Tube. Figures 1a, 1b, and 1c show the different configurations.
3. Different test conditions:
   a) with and without Back Panel of the Beranek Tube
   b) with and without Speaker Back Panel
   c) different Clamping Forces
   d) different Equalizer Settings
   e) with and without the Center Speaker

In Figure 1c a drawing of this Test Facility is represented, featuring the most important dimensions, components, and microphone positions. The "normal source microphone position" is related to the speaker baffle at all times. The "normal receiver microphone position" is always situated at a particular position in the Beranek Tube, as indicated in Figure 1c. For all tests that include a Panel, an .032 inch thick aluminum panel has been used, unless otherwise indicated.

For further details of this Test Facility, refer to Reference 1.

1. Source and Receiver Signals of the Microphones in the Beranek Tube

1.1 Without a panel installed

The spectra of the source and receiver microphone, as seen in Figure 1, are the flattest which can be obtained with the present, standard electronic equipment.

- Up till 400 Hz both signals are almost identical.
- The source signal shows two large peaks at 800 Hz and 2100 Hz respectively. A big dip is to be seen at a frequency of 1390 Hz.
- The receiver signal shows dips at 3700 Hz and 4800 Hz.

Conclusions: Up to 400 Hz the source and receiver signals are almost identical. Remarkable is the big dip in the source signal at 1390 Hz. (See also 4.1.)

1.2 The effect of the installation of a .032 inch thick, flat aluminum panel

The sound pressure level, when a panel is installed, is higher over the whole range of frequencies, except between 43 and 59 Hz (Figures 2 and 3).

- The source signal shows dips and peaks, up to 800 Hz, probably due to the panel mode frequencies.
- The receiver signal is lower in the range of frequencies up till 500 Hz , except in the neighborhood of 56 Hz, 150 Hz and 495 Hz.

Conclusions: It appears, as expected, that due to the installation of a panel, the measured sound pressure level of the source microphone is higher (also a reflected sound is measured) and the sound pressure level of the receiver microphone is lower. This is true, because the total pressure, measured by the microphones, will be approximately constant (In this case, the energy dissipation by the panel, absorption material and walls is not taken into consideration).

The dips in the source signal are due to the resonance modes of the panel. At a slightly higher frequency a peak in the receiver signal occurs. Also when a peak in the source signal occurs, a dip in the receiver signal is to be seen at a slightly higher frequency. The shift in frequency is probably due to energy dissipation of the panel.

2. The Effect of Different Noise Sources on the Sound Pressure Levels of the Source and Receiver Microphone

The noise sources are:

a) Pure Tone Generator (Figure 3)

b) White Noise Generator (Figure 4)

c) Real Aircraft Noise of a Cessna 172 in climb: 90 mph I.A.S. and 2550 RPM (Figure 5)

d) Real Aircraft Noise of a Cessna 172 in cruise: 117 mph I.A.S. and 2500 RPM (Figure 6)

Only the Beranek tube has been used for these measurements.

Using the White Noise Generator as the sound source (Figure 4), the output signal of both source and receiver microphone only differ in level from the output signals as obtained by using a Pure Tone Generator (Figure 3). The peaks and dips of the "White Noise Curve"

occur at the same frequencies as the peaks and dips of the "Pure Tone Noise Curve". The high peaks at a frequency of 60 Hz are due to the specific AC frequency of the electric mains.

The two "Aircraft Noise Curves" did not differ very much, except for a small shift in frequency, due to the difference in RPM of the propeller. Also the sound pressure level changed a little bit because the I.A.S. in both cases were not the same. (Figures 5 and 6.)

The "Aircraft Noise Curves" are basically the same as the "White Noise Curve" and the "Pure Tone Curve"; that is to say that the general shape of the curve, the peaks and dips, does not change. The propeller frequencies appear as clear peaks in the sound pressure level curve. Due to a different power setting, the "Aircraft Noise Curve", "White Noise Curve" and "Pure Tone Curve" differ in sound pressure level.

Conclusions: The use of the Pure Tone Generator as a sound source for Noise Reduction measurements appears to be representative for the sound excitation, as occurs in a real airplane. A minor wrinkling, due to the propeller frequency, on the sound pressure level curve can be neglected for the measurements in the Baranek Tube.

3. Effect of Equalizer Output Setting

An equalizer output setting of respectively 0 dB, 3 dB and 10 dB is used, and the result is shown in Figures 7, 8 and 9. It appears that this equalizer setting does not affect the path of the curve. The peaks and dips occur at the same frequencies. Only the sound pressure level differs a constant value.

Conclusions: The change in "dB reading" of the equalizer does not correspond with the change in sound pressure level of the microphone outputs. Although the paths of the curves do not change, the same equalizer setting is required for all tests, to facilitate comparison of the curves.

4. Effect of the Microphone Position in Longitudinal Direction and of the Installation of a Panel, for Different Test Configurations

The position of the microphone was varied in longitudinal direction for each of the following test configurations:

1. Only the Beranek Tube
2. The 30° Test Section plus the Beranek Tube
3. The Extension Tube plus the 30° Test Section plus the Beranek Tube
4. The Extension Tube plus the 40° Test Section plus the Beranek Tube
5. The 30° Extension Tube plus the Beranek Tube with a panel installed between them
6. The Extension Tube plus the 30° Test Section plus the Beranek Tube with a panel installed between the 30° Test Section and the Beranek Tube.

Taking a cross section, the microphone position is always in the center.

For each of the above mentioned test configurations the effect of the microphone position is described in the following:

4.1 Beranek Tube

Tests have been done with the microphone at distances of respectively 1 inch and 8 inches from the speaker baffle. The sound pressure

level curves for both microphone positions are identical up to 400 Hz (Figure 2). Above this frequency the sound pressure level of the microphone, closest to the source, is in general higher than the signal as indicated by the microphone at 8 inches from the speaker baffle.

A severe dip occurs at a frequency of about 1390 Hz in the signal of the microphone at a distance of one inch from the center speaker. The same dip occurs in the signal at the other microphone position but is less severe. This severe dip in the sound pressure curve is most likely caused by a transverse standing wave between the rigid parallel walls of the Beranek Tube. The walls at that cross section are not covered with sound absorption material. It is not possible yet to determine the normal frequencies of the Beranek Tube. The formula for the normal frequency in a rectangular enclosure as given by Reference 1:

$$f_n = \frac{c}{2} \quad \left(\frac{n_x}{\ell_x}\right)^2 + \left(\frac{n_y}{\ell_y}\right)^2 + \left(\frac{n_z}{\ell_z}\right)^2 \qquad (1)$$

where c = speed of sound [ft/s]

(n_x, n_y, n_z) = oblique modes of vibration, in which the component waves are oblique to all three pairs of the walls.

ℓ_x, ℓ_y, ℓ_z = the width, height and length of the enclosure. [ft]

It is assumed that all three walls have very small sound absorption characteristics. This is the case with the walls in X and Y direction in this cross section. But in the length of the Beranek Tube, a lot

of absorption material has been installed. So the effective length ℓ_z cannot be determined because the absorption coefficient is unknown. If there is no reflection at all from the back wall of the Beranek Tube, the mode could be either (3,2) or 2,3) (a square cross section), which corresponds with a frequency of 1353 Hz.

<u>Conclusions</u>: Up to 400 Hz, the output signal of both microphones is identical and is not a function of the distance in longitudinal direction (up to 8 inches from the speaker baffle). Above this frequency the sound pressure level is dependent on the position of the microphone and will, in general, increase with an increase of the distance between the microphone and the speaker baffle.

A severe dip occurs at a frequency of 1390 Hz in the 18 in. x 18 in. cross section, which is not covered with sound absorption material. If the distance to the speaker baffle becomes greater, the dip becomes less severe, due to sound absorption material, as installed around the microphone at a distance of 8 inches from the speaker baffle (normal receiver microphone position).

4.2 The 30° Test Section plus the Beranek Tube

To see the effect of changing the longitudinal distance between microphone and speaker baffle, tests have been done with the following microphone positions:

> Normal source microphone position at a distance of 1 inch from the source (Figure 10)
>
> Microphone at a distance of respectively 4 inches, 8 inches, 19 inches and 29 inches from the source (Figures 11-14)

Normal receiver microphone position at a distance of 45 inches from the source (Figure 15)

The microphone signal at one inch from the source (Figure 10) shows a severe dip at a frequency of 1080 Hz. This dip is most likely caused by a transverse standing wave, similar to the one as discussed in Section 4.1. The shift in frequency from 1390 Hz to 1080 Hz is due to the different dimensions of the cross section of the 30° Test Section (30 inches x 30 inches for the 30° Test Section, while 18 inches x 18 inches for the cross section of the Beranek Tube).

Up to 2000 Hz, the sound pressure level becomes in general lower as the distance between microphone and source increases. This is not true around a frequency of 52 Hz, where a small valley shows up in the sound pressure curve. The reason for this phenomenon could be a weak longitudinal standing wave of the (0,0,1) mode, which would have a normal frequency of 50 Hz according to Equation 1.

It can be noticed that between the frequencies of 90 Hz and 1000 Hz, the sound pressure level drops as a function of both position and frequency.

a) Position

In general, the sound pressure level will become lower if the distance to the source increases, because of energy absorption by walls and absorption material.

b) Frequency

The properties of the absorption material are dependent upon, among other things, the porosity of the material (Figure 16). If the porosity is relatively high--a characteristic of an open-cell material--the absorption will be low because the pressure variations

will move directly through the material without reduction. If the porosity is relatively low--a characteristic of a closed-cell material--the absorption will be low because the sound will reflect off the surface (Reference 2). In the facility of the Flight Research Laboratory, closed-cell absorption material has been used, because of the better sound absorption at low frequencies. The sound absorption will decrease above a frequency of 900 Hz, due to reflection of the sound. For the reasons mentioned above, the sound pressure level will be a function of the frequency, as it will drop between 90 and 1000 Hz. Below 90 Hz the sound absorption is too low to have much influence. Above 2000 Hz the sound absorption will be constant for any frequency.

Conclusions: Locating the microphone close to the source will cause a transverse standing wave, resulting in a severe dip in the sound pressure curve around 1080 Hz. Varying the microphone position in longitudinal direction will vary the sound pressure level as a function of position and as a function of the frequency, especially between 90 Hz and 2000 Hz due to absorption material characteristics.

4.3 Extension Tube plus 30° Test Section plus Beranek Tube

In this configuration, measurements have been done for the following microphone positions:

> 0.1 inch, 1 inch (normal source microphone position), 4 inches, 8 inches, 16 inches, 34 inches, 50 inches, 60 inches, and 75.25 inches (normal receiver microphone position). The corresponding graphs are numbered from 16 to and including 23.

The sound pressure signal obtained extremely close to the loudspeaker (0.1 inch) is identical to the signal measured at a distance of 1 inch from the source. They include a severe dip at a frequency of 1320 Hz, which is about the same frequency as noticed in Section 4.1. The reason is that the cross sections of both the Extension Tube and the Beranek Tube have the same dimensions. The transverse standing wave, that will show up at the same frequency as the one discussed in this Section 4.1, will disappear when the distance to the source is increased (Figures 16 and 17).

In the following the sound pressure level as a function of the frequency will be discussed for different frequency ranges:

In the frequency range from 20 Hz to 36 Hz, the sound pressure level increases with an increase of the distance between microphone and speaker baffle (Figures 16-23).

Between 36 Hz and 90 Hz the sound pressure becomes lower till a distance of 34 inches from the source has been reached. By moving the microphone further than 34 inches from the speakers, the sound pressure level shows an increase, and the slope of the curve becomes steeper again. As the increments and decrements in this region are small and a sine-like function of the distance, a weak longitudinal standing wave is expected at a frequency of 64 Hz (Figures 16-23).

The influence of the absorption material between 90 Hz and 1000 Hz is to be seen in Figures 16-23 and needs the same explanation as given in Section 4.2.

Above 1000 Hz a lower sound pressure level will be measured, when these measurements are done at a greater distance from the speaker baffle. This is generally true, although it does not always work out in the higher frequencies.

Conclusions: Basically the same characteristics of the sound pressure level as function of frequency and position for this configuration have been found as for the configuration of the 30° Test Section plus Beranek Tube. Below 36 Hz and above 1000 Hz, the sound pressure level decreases with an increase in distance to the source, as one could expect. A weak longitudinal standing wave showed up at 64 Hz, while close to the source, in the 18 inch x 18 inch cross section which has no absorption materials, a transverse standing wave is noticeable at a frequency of 1320 Hz.

Finally the influence of closed-cell absorption material became visible between the frequencies of 90 Hz and 1000 Hz as a function of the distance to the noise source.

4.4 Extension Tube plus 40° Test Section plus Beranek Tube

Figures 24 through 29 show the sound pressure level as function of the frequency for different distances from the microphone to the source. The test data throughout the range of distances are identical to the results obtained with the configuration of the Extension Tube plus 30° Test Section plus Beranek Tube in Section 4.3.

Conclusion: There is no difference in test data and results by using either the 40° Test Section or the 30° Test Section in combination with Extension Tube and Beranek Tube.

4.5 30° Test Section plus Panel plus Beranek Tube

The same configuration as in Section 4.2 has been used, but now a panel has been installed. Tests have been done for microphone positions, at a distance of respectively 1 inch (normal source microphone

position), 4 inches, 8 inches, 19 inches and 29 inches from the speaker baffle. These are the same microphone positions as used in Section 4.2. The influence of the panel is clearly observable: A dip in the sound pressure level curve between 70 Hz and 120 Hz, which is dependent on the position of the microphone in the 30° Test Section (Figure 30 through 34). At higher frequencies, above 1000 Hz the vibration of the panel is to be seen as an oscillation in the sound pressure level curve. The dip at 1080 Hz, due to a transverse standing wave, has disappeared.

A comparison of Figures 30 through 34 (a panel installed) with Figures 10 through 14 (same configuration, but without a panel) shows that the <u>average</u> sound pressure level of the source microphone is not affected by reflection off the panel surface. For the definition of Transmission Loss, it was assumed that all the incident sound energy is either transmitted or reflected by the panel. This should cause a pressure increase due to this reflection, and for this reason one could expect a higher sound pressure level. Figures 15 and 35 show that, if a panel is installed, the sound pressure level at the receiver side drops considerably. If the average sound pressure level at the source side of the panel does not change, the sound energy has to be absorbed, according to energy laws. This energy dissipation will be due to the panel vibration (including edge conditions) and the characteristics of the absorption material.

In the foregoing, <u>average</u> sound pressure levels have been discussed, since the influence of the panel is obvious. For the influence of a change in the microphone position on the sound pressure level, reference may be made to Section 4.2, as these characteristics are similar.

Conclusions: The conclusions will be given in Section 4.6.

4.6 Extension Tube plus 30° Test Section plus Panel plus Beranek Tube

The effect of changing the microphone position at the source side of a panel on the sound pressure level as function of the frequency is to be seen in Figures 36 through 40. Tests have been done with the microphone at a distance of respectively .1 inch, 1 inch, 16 inches, 34 inches, 44 inches, 61 inches and 66 inches from the source.

The characteristics of the change in sound pressure level as function of the distance, found in these tests, are basically the same as found in tests in Section 4.3. In this section the same configuration has been used, but there was no panel installed.

To find the influence, due to the installation of a panel, the following figures are comparable: Figures 16 and 36, 17 and 37, 20 and 38, and finally 21 and 29. It can be seen that over the whole range of frequencies, the average sound pressure level is the same, with or without a panel installed. In the lower frequencies (below 200 Hz) the signal is somewhat affected by reflections off the panel and probably by an "oilcanning" of the panel in the neighborhood of its own resonance frequency. Above 7000 Hz the vibration of the panel itself is noticeable and is superimposed at the sound pressure level curve of Section 4.3 (no panel installed, but the same configuration).

Conclusions: The influence of the microphone position on the sound pressure level, as function of the frequency, for each of the configurations in Sections 4.5 and 4.6, is similar to the characteristics of the configurations in Sections 4.2 through 4.4.

The average sound pressure level is not changing because of the installation of a panel. The assumption that all the incident sound is either transmitted or reflected by the panel appeared not to be true.

However, the sound pressure level is affected by the panel in the lower frequencies, due to reflections and an "oilcanning" of the panel near its own resonance frequency. In the higher frequencies (> 1000 Hz) the vibration of the panel is to be seen as a superposition on the sound pressure level curve as obtained when no panel was installed.

5. Effect of Various Microphone Positions in a Cross Section for Different Test Configurations

The speaker box contains nine evenly spaced loudspeakers (Figure 41). In the following, the speaker numbers of figure 41 will be used. It is assumed that in a cross section in front of the speaker baffle a plane, free progressive wave is propagated. The wave is progressing in only one direction. If the sound pressure is the same in every point of the cross section, a plane wave is propagated. This has been investigated for different test configurations.

5.1 Beranek Tube, no Panel installed

In order to see if the sound pressure level is the same in every point of a cross section, measurements have been done at a distance of 1 inch from the speaker baffle, at various locations. The results are shown in Figures 42 through 45 for microphone positions of respectively: in front of speaker #5, in the middle of speakers #4 and #5, in the middle of speakers #1 and #2, and in front of speaker #8.

Up to 650 Hz the sound pressure level curves for all different locations are almost identical (Fiugres 42 and 45). Above 650 Hz the sound pressure level as function of frequency is different for all four different measurement locations. In front of speakers #5 and #8, big dips are to be noticed around 1850 Hz and 3000 Hz, and some minor dips above 3000 Hz. Measuring between a different pair of loudspeakers changes the sound pressure level at a certain frequency, but the peaks and dips occur at almost the same frequency (Figures 43 and 44). Peaks show up at about 850 Hz, 1800 Hz, 2450 Hz, 3300 Hz and 3900 Hz, while dips are to be seen at 1300 Hz, 2200 Hz, 2800 Hz, 3500 Hz and 4600 Hz.

Conclusions: Below 650 Hz, in the region of main interest, the sound pressure level curves are almost identical. Therefore, a plane wave approximation in this frequency range is justified. Above 650 Hz there are considerable discrepancies due to a different microphone position in the same cross section. Therefore, it would not be correct to assume a plane wave in this region. Although the sound pressure level is not the same for measurements at the same microphone position to the different loudspeakers, the characteristics (peak and dips) of the loudspeakers related to the location of the measurements are quite similar. Changes in these characteristics by measuring in between two loudspeakers may be caused by interference of the two signals.

5.2 Extension Tube plus 30° Test Section plus Beranek Tube

In Chapter 4 it appeared that the sound pressure level curves at distances of .1 inch and 1 inch from speaker #5 were identical

(Figures 16 and 17). To make sure this is also valid for the same distances in front of speaker #4, measurements have been done for these microphone positions. Below 500 Hz this statement appeared to be true, as is to be seen in Figures 46 and 47. However, for the higher frequencies above 500 Hz, not only does the sound pressure level differ, but also the big dip measured at a distance of 1 inch did not show up in the results of the measurements done at .1 inch in front of speaker #4. Instead of the peak at 4400 Hz for the .1 inch microphone position, a dip is to be noticed at 4700 Hz in the signal measured by the microphone at 1 inch from speaker #4.
Also a comparison has been made between the signals obtained by microphone positions at .1 inch distance right in front of the speakers #4 and #8 (Figures 46 and 48). Up to 400 Hz the signals are quite similar again. Above this frequency the sound pressure level differs, but dips and peaks are associated with the same frequencies.
Conclusions: The sound pressure level can, even close to the speaker, be a function of the distance to this speaker, above frequencies of 500 Hz. Compared to another speaker, the sound pressure level is similar up to Hz. Above this frequency the sound pressure level differs from speaker to speaker, so in this cross section a plane wave cannot be generated for that frequency range. It is recommended that more tests be done in order to be able to explain these differences.

5.3 Extension Tube plus 30° Test Section plus Panel plus Beranek Tube

In this section the sound pressure level in various points of two different cross sections have been reviewed, one cross section close to the speaker baffle and one cross section close to the panel.

5.3.1 Cross section near the speaker baffle

Again the signals of the microphones at a distance of respectively .1 inch and 1 inch from speaker #4 are compared (Figures 49 and 50). The results are similar to those obtained in Section 5.2. Up to 500 Hz the sound pressure level curves are identical; but above these frequencies the sound pressure level as well as the frequencies, where the peaks and dips occur, differ for the two microphone positions.

Comparing the signals of the microphone in front of speakers #4 and #8, both at a distance of .1 inch from the speakers, it can be noticed that both sound pressure level curves cover each other below a frequency of 400 Hz (Figures 59 and 51). Above 400 Hz the characteristics of the curves are the same (peaks and dips show up at the same frequencies), but the sound pressure level as a function of the frequency differs by several dB's.

Conclusions: The same conclusions can be stated as under Section 5.2. The approximation of a plane wave can be made below the frequency of 400 Hz, the main frequency range of interest. Above this frequency of 400 Hz, the same approximation would be very inaccurate. Notice the superposition of the panel vibrations on the sound pressure level curve at high frequencies. Morc tests will be needed to explain this phenomenon.

5.3.2 Cross section near the aluminum panel

For future tests it will be very important to know if a plane wave will hit the panel in the configuration of the Extension Tube plus 30° Test Section plus Beranek Tube. In order to investigate this, measurements have been done in a cross section at a distance

of two inches from the panel for the following microphone positions in this cross section:

1. In front of speaker #5 (Figure 52)
2. Centered, two inches from the top (Figure 53)
3. Two inches from the left side wall, two inches from the top (Figure 54)
4. Centered, five and a half inches from the bottom (Figure 55)
5. Centered, two inches from the bottom (Figure 56)
6. Two inches from the right side wall, two inches from the bottom (Figure 57)
7. Five and a half inches from the right side wall, five and a half inches from the bottom (Figure 58)

Below 850 Hz the sound pressure level curves are almost identical. Above this frequency, changes in sound pressure level as well as in the path of the curve will occur.

Transverse standing waves will influence the path and the level of the sound pressure level curves above 850 Hz. Also the sound absorption material which covers the side walls will have its effect on the sound pressure level. Above this frequency the vibration of the panel becomes visible as a fast oscillation which is superposed on the sound pressure level curves.

Conclusions: Below the frequency of 850 Hz the assumption that a plane wave will hit the panel is justified. Above this frequency the assumption of a plane wave is not tolerable any more. In this region the vibration of the panel is visible, and it is likely that reflections of this vibration will disturb the uniform pressure distribution in a cross section in front of the panel.

6. Effect of Different Clamping Forces for Respectively a .032 Inch Thick and a .016 Inch Thick Aluminum Panel

To investigate the influence of different clamping forces on the sound pressure levels in front of a panel and behind a panel, measurements have been done clamping the panel between the speaker box and the Beranek Tube while using torque settings on the bolts of respectively 25 in-lb (as used for all previous tests), 50 in-lb and 80 in-lb. A higher torque setting than 80 in-lb could not be applied to the bolts, because otherwise the thread could be damaged. For the tests, two panel thicknesses were used.

6.1 .032 Inch Thick Panel plus Beranek Tube

Above the frequency of 200 Hz, the signals for all three different clamping forces are identical (Figures 59, 60 and 61). Analyzing the receiver signal, it appears that the sound pressure level at a frequency of 54 Hz is slightly lower as the clamping force is increased. Also the first dip in the sound pressure level curve shifts to higher frequencies. Both phenomena are to be explained by the apparently higher rigidity of the panel. Below 65 Hz the sound pressure level as function of the frequency becomes higher, if the clamping forces are increased. Between 65 Hz and 115 Hz the opposite pahhens. It is not quite clear what the reason could be. Between 115 Hz and 200 Hz the difference between the different curves can be ignored. Conclusions: Above a frequency of 200 Hz the edge conditions of the panel can be assumed to be almost clamped. Investigation into the conditions of entirely clamped conditions is needed. Below the frequency of 200 Hz it is not possible to predict the edge conditions.

In this frequency range the sound pressure level curve (especially the curve measured by the source microphone) is a function of the torque setting.

6.2 .016 inch thick Panel plus Beranek Tube

As may be seen in Figures 62, 63, and 64, the influence of the clamping force on the sound pressure level of the panel is considerable higher when a thinner (.016 inch thick) panel is tested. The sound pressure level curves show small discrepancies among them, as well for the receiver as for the source microphone. These discrepancies are relatively small for the receiver microphone for all frequencies, but the signal of the source microphone is much more influenced by the clamping forces applied to the panel. Below a frequency of 340 Hz, the sound pressure level curve cannot be predicted, because the exact edge conditions of the panel cannot be determined.

Conclusions: The edge conditions of a thin panel (.016 inch thick) cannot be known exactly, because they are somewhere between clamped and simply supported. The sound pressure level curve can change with every test, because the edge conditions can change during the measurements. The torque setting of 25 in-lb, as used in previous tests, is too low in order to be sure that accurate results will be obtained. Real clamped edge conditons are recommended.

7. Influence of the Back Panel of the Beranek Tube for Different Test Configurations

To investigate the influence of the back panel of the Beranek Tube on the sound pressure levels at both sides of the panel, tests

have been done for the following test configurations:

7.1 Beranek Tube, no Panel installed

Figure 65 shows the signals received by the source and receiver microphone for the normal microphone positions. The configuration consists of the Beranek Tube, no Panel installed. The sound pressure level curves of both microphones are compared to the signals of both microphones at the same positions in the same configuration, except that the back panel of the Beranek Tube has been removed (Figure 66). The two microphone signals with and without back panel cover each other completely.

Conclusion: It appears that installation of a back panel has no influence on the sound pressure levels measured by the two microphones. The conclusion is that the absorption material in the Beranek Tube reduces the sound pressure level amplitude of reflecting or standing waves so much that no higher pressure is measured by the microphones.

7.2 Beranek Tube, with a .032 aluminum Panel installed

The source and receiver microphone signals are compared for the configuration mentioned above, with and without the back panel of the Beranek Tube. The signals are again identical (Figures 67 and 68).

Conclusion: The conclusion can be the same as in Section 7.1.

7.3 Extension Tube plus 30° Test Section plus Beranek Tube

The tests have been done with "normal" microphone positions. Comparison of Figures 22 and 69 show that also in this configuration the influence of the back panel on the source and receiver microphone

signals can be ignored.

Conclusion: No influence of the back panel of the Beranek Tube has been measured, so the conclusion has to be the same as in Sections 7.1 and 7.2.

7.4 Extension Tube plus 30" Test Section plus Panel plus Beranek Tube

The same configurations as in Section 7.3 are tested, except that now a .032 aluminum panel has been installed. The source and receiver microphone signals in configurations with and without a back panel in the Beranek Tube cover each other completely, as is apparent in Figures 70 and 71.

Conclusion: In no configuration has any influence been measured of the back panel of the Beranek Tube upon the sound pressure level signals of source and receiver microphones. The amplitudes of reflecting and standing waves are reduced sufficiently so that they do not affect the sound pressure as measured by the microphones.

8. Tests Without the Speaker Back

Tests with the microphone position in front of speaker #5 showed a big dip at a frequency of 1380 Hz (Figure 1). To investigate if this dip is caused by a standing wave (as suggested in Chapter 1) or by the properties of speaker #5, tests have been done with all the nine speakers connected; and these are compared with tests where speaker #5 is disconnected. For this purpose the speaker back had to be removed, which provided the opportunity to analyze the influence of the presence of this speaker back. First the influence of the presence of the speaker back will be determined, and afterwards the effect of disconnecting speaker #5 will be analyzed.

8.1 The influence of the speaker back on the signals of the microphones at the normal source and receiver microphone positions for a configuration of Extension Tube plus 30° Test Section plus Beranek Tube

8.1.1 Normal source microphone position

Below a frequency of 50 Hz, the sound pressure level, measured with the speaker back removed, is a little bit higher than with the speaker back still at its original position (Figures 72 and 73). In the mid-range frequencies (110 Hz-600 Hz) a fast oscillation in the sound pressure level curve is to be seen, if the speaker back is removed. This can be caused by the vibration of the speaker cone paper, which motion will be hardly damped, when the speaker back has been removed. Between 50 Hz and 110 Hz and above 600 Hz, the sound pressure level curves in both configurations cover each other.

Conclusion: The variations in the sound pressure level curve, due to the removal of the speaker back, are minor. Except in the frequency range of 20 Hz-50 Hz, where the difference between the curves corresponds with a couple of dB's.

8.1.2 Normal receiver microphone position

By comparing Figures 74 and 75, the same phenomena can be noticed as in Section 8.1.1. Below a frequency of 60 Hz, the signal measured in the configuration with no speaker back appeared to be higher than in the case where the speaker back was still installed.

According to the formula: $\lambda = c/f$, where f = frequency (Hz)
c = speed of sound (ft/sec)
λ = wavelength (ft)

with c = 1120 ft/sec (speed of sound in air) the wavelength will be at least: $\lambda = 16.7$ ft. Probably reflections off the walls of the test laboratory will affect the sound pressure level as measured by the microphone.

Between 110 Hz and 600 Hz the vibration of the speaker cone paper, as mentioned in Section 8.1.1, shows up again in the sound pressure level curve. In the other frequency ranges the signals as measured in both configurations are identical.

Conclusion: Discrepancies in comparing the two curves in both configurations (with and without speaker back) are very small, except in the frequency range below 60 Hz. Future tests without speaker back can be done without applying any corrections above 60 Hz. Below this frequency one must be aware that there is an influence on the sound pressure level.

8.2 The influence of speaker #5 on the sound pressure level curves of the source and receiver microphone signals for different configurations

Tests have been done in different configurations with and without speaker #5 connected and all without the speaker back installed. Figure 76 gives the scheme of the electric wiring if all nine speakers are connected and when speaker #5 is disconnected.

8.2.1 Beranek Tube

Comparing the signals as measured by the source microphone (close to speaker #5) with and without this speaker #5 connected gives the following changes in the sound pressure level curve: (Figures 77 and 78).

up to a frequency of 800 Hz the sound pressure level drops a constant number of dB's for every frequency.

The big dip at 1380 Hz disappears when speaker #5 is disconnected, and above 800 Hz the sound spectrum becomes quite different. The signals as measured by the receiver microphone also show the constant difference below 500 Hz. Above this frequency the sound pressure level difference varies, but the characteristics of the sound pressure level curves remain the same (peaks and dips show up at the same frequency).

Conclusion: The big dip can be caused by either a transverse standing wave or by a property of speaker #5. Below the frequency of 500 Hz the sound pressure level signals, as measured at the normal source and receiver microphone positions, differ a constant value, due to less sound energy generated by eight instead of nine speakers. As seen in Chapter 5, a plane wave approximation is justified. In the higher frequencies at a short distance from the panel it is not correct to assume a plane wave. Therefore, without having a plane wave, the sound spectrum will vary if the sound pressure of speaker #5 is not the most important one any more; but on the contrary, the sound pressures of the other speakers are measured by the microphone.

At a greater distance from the panel, a plane wave may be expected also for the higher frequencies, as concluded in Chapter 5. In this way the behavior of the sound pressure level curve as measured by the receiver microphone can be explained.

8.2.2 Beranek Tube with a Panel installed

As many be seen in Figures 79 and 80, the installation of a panel does not influence the basic properties of the sound pressure level curves, which are discussed in Section 8.2.1. The characteristics of the sound spectrum as measured by the source microphone, with and without speaker #5 connected, are similar up to 900 Hz. The characteristics of the sound spectrum as measured by the receiver microphone are similar over the whole range of frequencies. The sound pressure level as function of the frequency drops when speaker #5 is disconnected. Conclusion: The same conclusions can be made as in Section 8.2.1, because the installation of a panel does not affect the basic properties of the sound pressure level curves as measured by the source and receiver microphone with and without speaker #5 connected.

8.2.3 Extension Tube plus 30° Test Section plus Beranek Tube for various distances from microphone to sound source

Using the configuration of Extension Tube plus 30° Test Section plus Beranek Tube, tests have been done for microphone positions at distances of respectively 1 inch (normal source microphone position), 8 inches, 34 inches from the source and at the normal receiver microphone positions (Figures 81 through 84). The results are compared to those obtained by tests using the same configuration, the same microphone positions, but with speaker #5 disconnected (Figures 85 through 88). At a short distance from the speaker baffle, the results are similar to those obtained in sections 8.2.1 and 8.2.2: Below the frequency of 800 Hz, the paths of the sound pressure level curves are of the same form, only when speaker #5 is disconnected the sound pressure

level drops a few decibels. Above this frequency of 800 Hz, the sound spectra are quite different because in this frequency range, a plane wave approximation is not justified (see also sections 8.2.1 and 8.2.2). The big dip at 1380 Hz disappears when speaker #5 is disconnected.

Increasing the distance between the microphone and source means that circumstances are more favorable for a plane wave approximation over the whole range of frequencies (Figures 83, 84, 87 and 88). This results in a similar sound spectrum for tests, with and without speaker #5 connected, for all the considered frequencies, only the sound pressure level will differ an almost constant value.

The dip, measured at a frequency of 1380 Hz close to the source disappears when the distance from microphone to source is increased. Disconnecting speaker #5, the dip at 1380 Hz disappears, but shows up again by increasing the microphone position to a distance of 8 inches from the source. This indicates that this dip cannot be just a speaker #5 property. As already mentioned in section 4.7, the dip is assumed to be caused by a transverse standing wave in that cross-section.

<u>Conclusions</u>: For the configuration of Extension Tube plus 30° Test Section plus Beranek Tube, the effect of disconnecting speaker #5 is the following: At short distances from the speaker baffle in front of speaker #5, the sound pressure level drops an almost constant amount of decibels for frequencies up to 800 Hz. The same thing happens at large distances from the source for the frequency range from 20 Hz to 5000 Hz. At short distances and above 800 Hz, the effect is unpredictable, due to the difference in sound pressure in various points of a cross section. The dip in the sound pressure level curve is assumed to be caused by a transverse standing wave in the cross section where the signal is measured.

8.2.4 Extension Tube plus 30° Test Section plus Panel plus Beranek Tube for various distances from microphone to sound source

Wondering what the influence of a panel was like on the tests as described in section 8.2.3, measurements have been done while using the same microphone positions, the same test conditions and the same configuration, but now with a panel installed between the 30° Test Section and the Beranek Tube.

The influence of the panel on the results as obtained in section 8.2.3 consist of a higher measured sound pressure in front of the panel and a lower measured sound pressure behind the panel for all conditions. However, the mutual comparison of the sound pressure level curves with and without speaker #5 connected remains basically the same. In the higher frequencies above 1200 Hz, the vibration of the panel is visible as a fast oscillation in the sound pressure level curve.

<u>Conclusion</u>: The installation of a panel does not affect the conclusions as made in section 8.2.3. Therefore, the same conclusions as in this section are operative.

9. Conclusions

Following the discussions in all the sections, conclusions were given concerning the influence of microphone positions, configurations and conditions of the Test Facility on the measured sound pressure levels.

These conclusions can be summarized as follows:

1. Although all the walls have been covered very carefully with high quality absorption material, standing waves in between and reflections off the walls and absorption wedges cannot be prevented.
2. In addition, inside the Beranek Tube, behind the test panel, standing waves occur and reflections influence the signal measured by the receiver microphone.
3. Energy dissipation by absorption material, walls and test panel is not neglibible.

In defining Transmission Loss the assumptions are made that all the sound energy is either transmitted or reflected by the panel and that no reflections nor standing waves are present in the room behind the panel. Conclusions 1, 2 & 3 do not agree with the above-mentioned assumptions.

4. The plane wave approximation is only justified below a frequency of 800 Hz at short distances from the speaker baffle. It is also justified over the entire frequency range (20 Hz-5000 Hz) if the distance from the source is at least 34 inches.
5. The use of a Pure Tone Generator as a sound source, instead of White Noise or Real Aircraft Noise, appeared to be reasonably representative for the sound excitation, as it occurs in a real airplane.
6. The microphone position (Chapter 4) has its greatest influence on the measured sound pressure level in the frequency range between, roughly, 150 Hz and 800 Hz.

7. Individually each of the nine loudspeakers has its own frequency response characteristics.

8. Possible reflections off the back panel of the Beranek Tube are not measured by the receiver microphone. Since a standing wave is measured with and without a back panel, the absorption material reduces the reflecting sound energy to zero. In addition, the walls of the laboratory room can also serve as reflection surfaces.

9. Above a frequency of 60 Hz the effect of removing the speaker back panel is minor. Below this frequency a change in sound pressure level is measured by the microphone. Because of the large wavelengths in this low frequency region, it is assumed that this is due to reflections off the laboratory room walls.

10. Using the 40° Test Section instead of the 30° Test Section, as an additional extension tube, had no effect on the test results.

11. The properties of the Acoustic Panel Test Facility are hard to define. Edge conditions of the test panels are <u>somewhere</u> between clamped and simply supported. The absorption material absorbs quite a lot of the sound energy, but <u>not all</u> the sound energy is absorbed. It is not known <u>how much</u> sound reflects from the panel, the walls and the sound absorption materials (at higher frequencies). This complicates any comparison of measured sound transmission with theoretical predictions.

10. Recommendations

As a result of the investigation as described in this report, the following recommendations are made:

1. As mentioned in the Conclusions, the assumptions made to define Transmission Loss appear to be incorrect for the Test Facility configurations studied in this report. The Transmission Loss coefficient is defined as the ratio of the transmitted flow of sound energy to the incident flow of sound energy. The source microphone measures incident plus reflected sound energy.

   If the assumptions that:

   a. All the sound energy is either transmitted or reflected

   b. No reflections are present in the room behind the test panel

   are incorrect, then the incident flow of sound energy cannot be calculated any more.

   Therefore it is recommended that, for future measurements in the Acoustic Test Facility, the transmission characteristics through a test panel be described by "Noise Reduction" instead of by "Transmission Loss."

   Noise Reduction is a widely used expression and is defined by the difference in sound pressure level measured at both sides of the test panel.

   Further investigation is needed to determine the consequences of the foregoing on the Transmission Loss curves, obtained from previous tests.

   It is recommended that all "Transmission Loss Curves" from these previous tests be changed into "Noise Reduction Curves."

2. It is not recommended that tests be done in the frequency range above 800 Hz, if a microphone is located within 8 inches of the speaker baffle. In this region a plane wave approximation is not justified.

   The exact microphone position, from where a plane wave approximation is valid for the frequency range from 20 Hz to 5000 Hz, has to be determined. This microphone position is situated between 8 inches and 34 inches from the speaker baffle.

3. Between 150 Hz and 800 Hz, a change in microphone position causes a change in sound pressure level, due to a longitudinal standing wave (Figures 16 through 23). These data suggest that the microphone position should be within .25 inch to get results which do not differ more than .25 dB.

4. Figures 3.3 through 3.10 in Reference 1, show the difference in sound pressure level of the nine loudspeakers. One speaker was taken as a reference. It is recommended that if tests have to be compared, with microphone positions in front of different speakers and at a short distance, the difference obtained from Reference 1 is to be taken into account.

5. To compose theoretical predictions related to the Acoustic Panel Test Facility, assumptions have to be made to simplify the model. An example is the assumption of either simply supported or clamped edge conditions. Another assumption would be that the walls of the tube either reflect all the sound or all the sound energy is absorbed. To validate these assumptions, the Test Facility has to be modified as follows:

a. The use of a steel frame for clamped edge conditions;

b. Removal of all the sound absorption material to obtain walls that will reflect almost all the sound.

The first modification is easily carried out. Tests with clamped edge conditions for the Test Panel will be done in the near future. The second modification could also be realized. However, with the sound absorption material removed, the remaining Tube has an unfavorable shape which does not represent simple initial conditions. The width and height are not uniform along the length (Figure 1c). The length of the Test Tube is too great; standing waves already occur above a frequency of 39 Hz (Configuration: Extension Tube plus 30° Test Section plus Beranek Tube.)

To get simple initial conditions for theoretical predictions, the Test Facility would have to be changed drastically. It is not recommended that this be done at this point in time.

It is recommended that the Test Facility be kept in use in its present condition. Test results can be compared with one another and properties of the Test Panels can be related to a flat, .032 inch thich aluminum panel.

6. For any series of measurements in the same configuration and for any position of the receiver microphone, a test run must be done without a Test Panel installed.

If the test results for the measurements when no Panel is installed match, one can be sure that the Noise Reduction through this Panel is comparable for each series of tests.

11. References

1. Henderson, T. D., "Design of an Acoustic Panel Test Facility" University of Kansas, M.E. project report, 1977.

2. Beranek, L. L., Noise and Vibration Control, McGraw-Hill Book Co., New York, 1971.

3. Emme, J. H., Plackford H. L., Inc., "Composite Materials for Noise and Vibration Control", Sound and Vibration, Reprint 1.

Figures

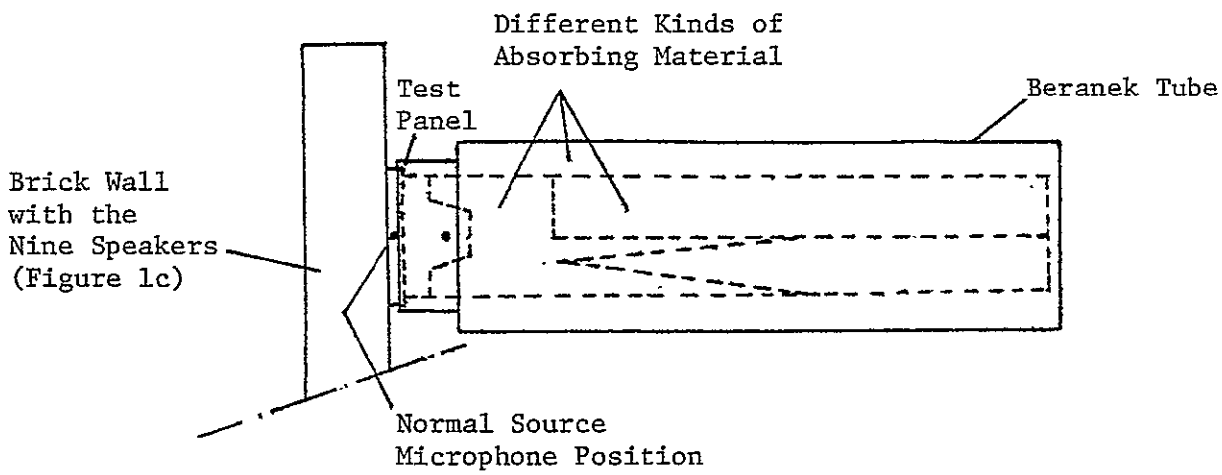

Figure 1a: The Beranek Tube as Basic Configuration
for the Acoustic Panel Test Facility

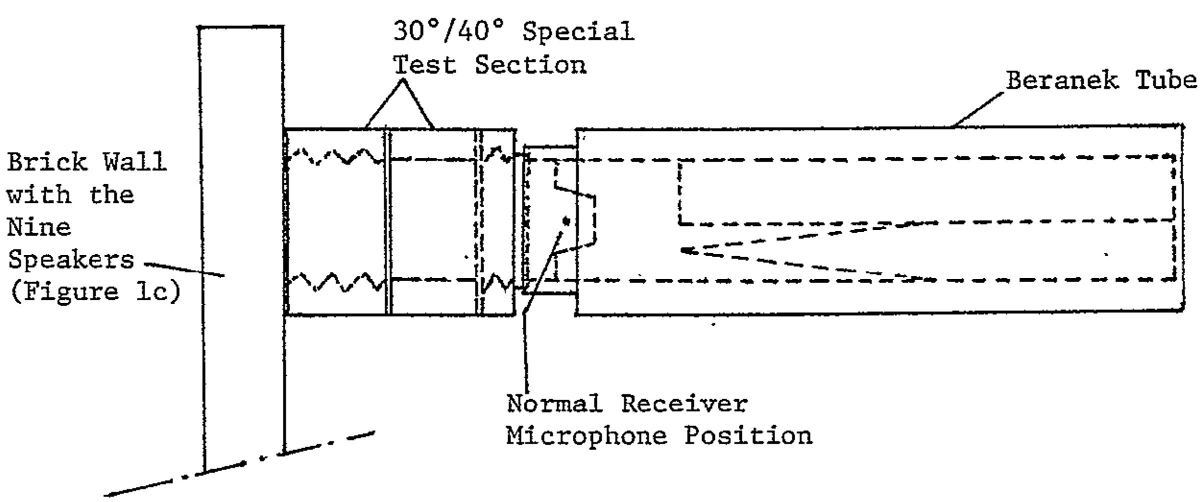

Figure 1b: The Configuration of Beranek Tube
plus 30°/40° Test Section

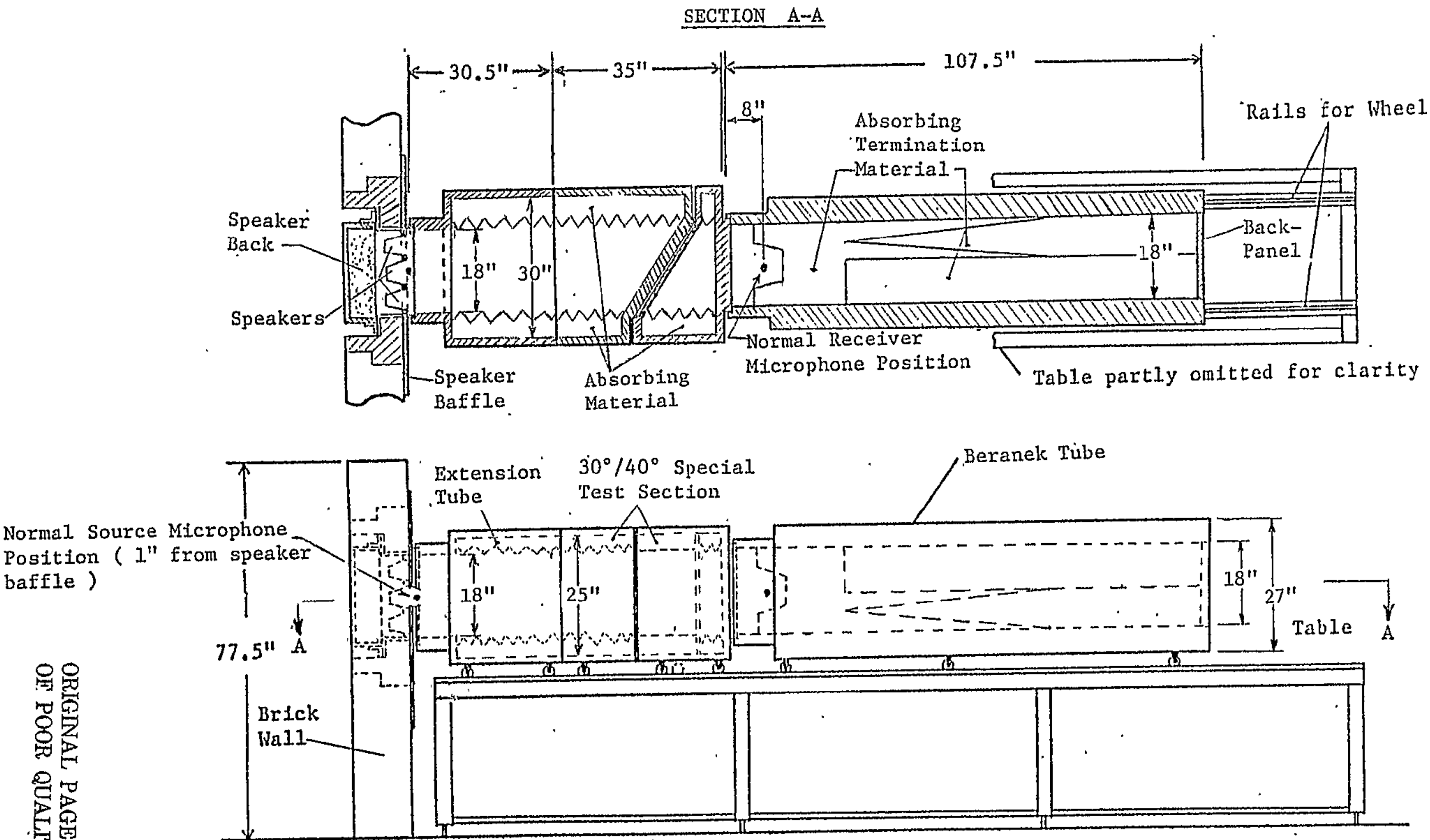

Figure 1c: Acoustic Panel Test Facility as Used by the KU-FRL Noise Research Team.

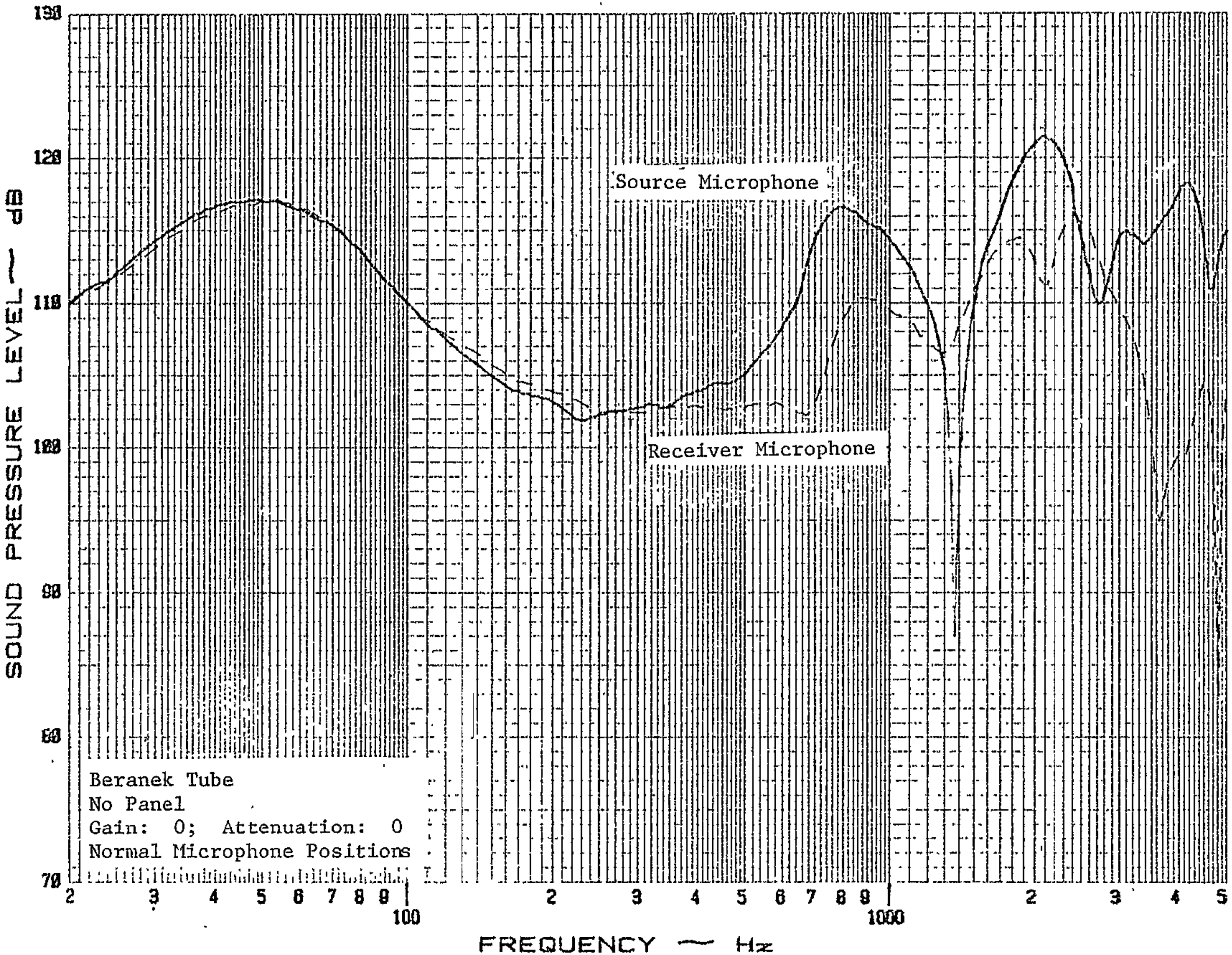

Figure 2: Experimental Sound Pressure Levels for Normal Source and Normal Receiver Microphone Position.

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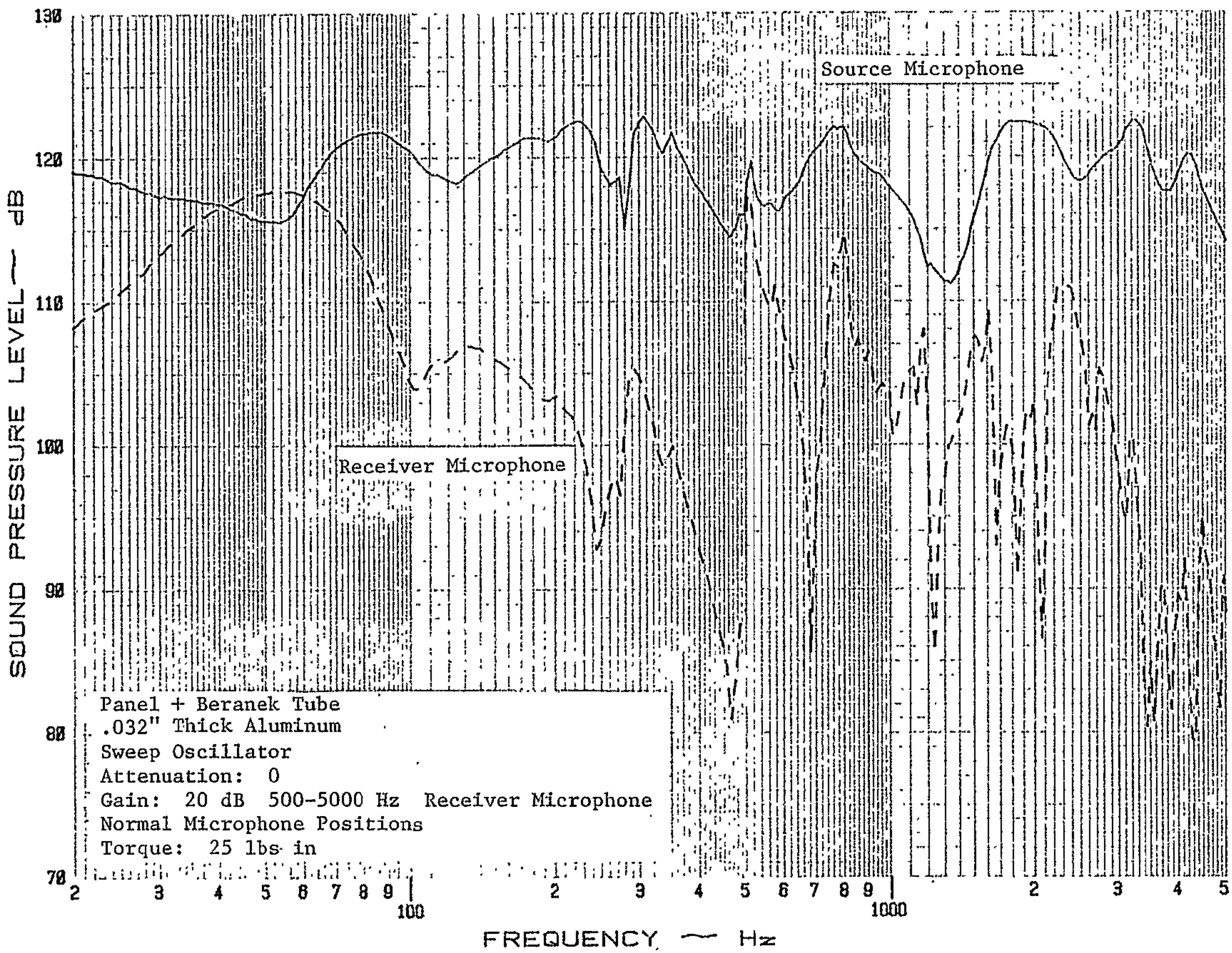

Figure 3: Experimental Sound Pressure Levels Using a Pure Tone Generator as Sound Source.

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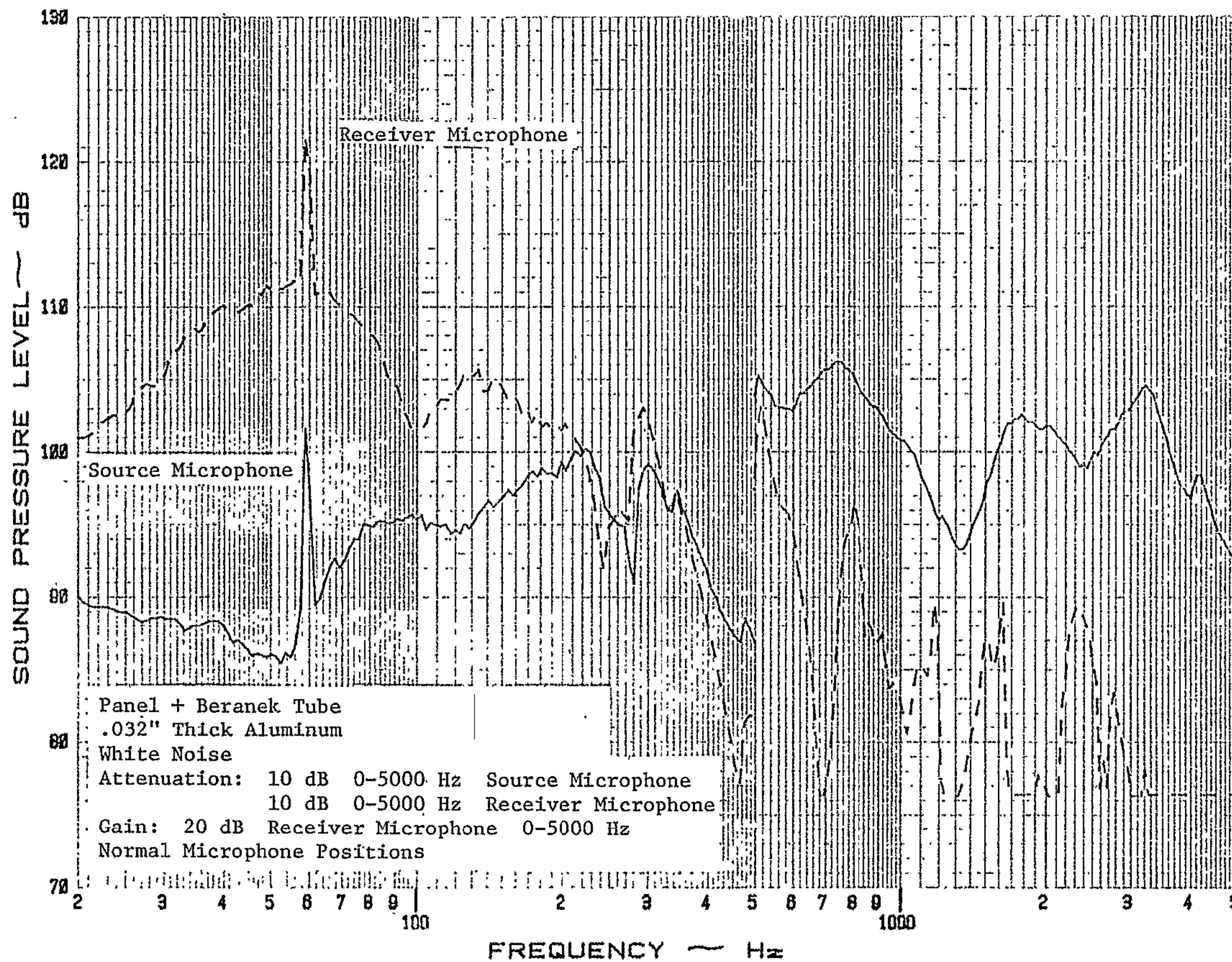

Figure 4: Experimental Sound Pressure Levels Using a White Noise Generator as Sound Source.

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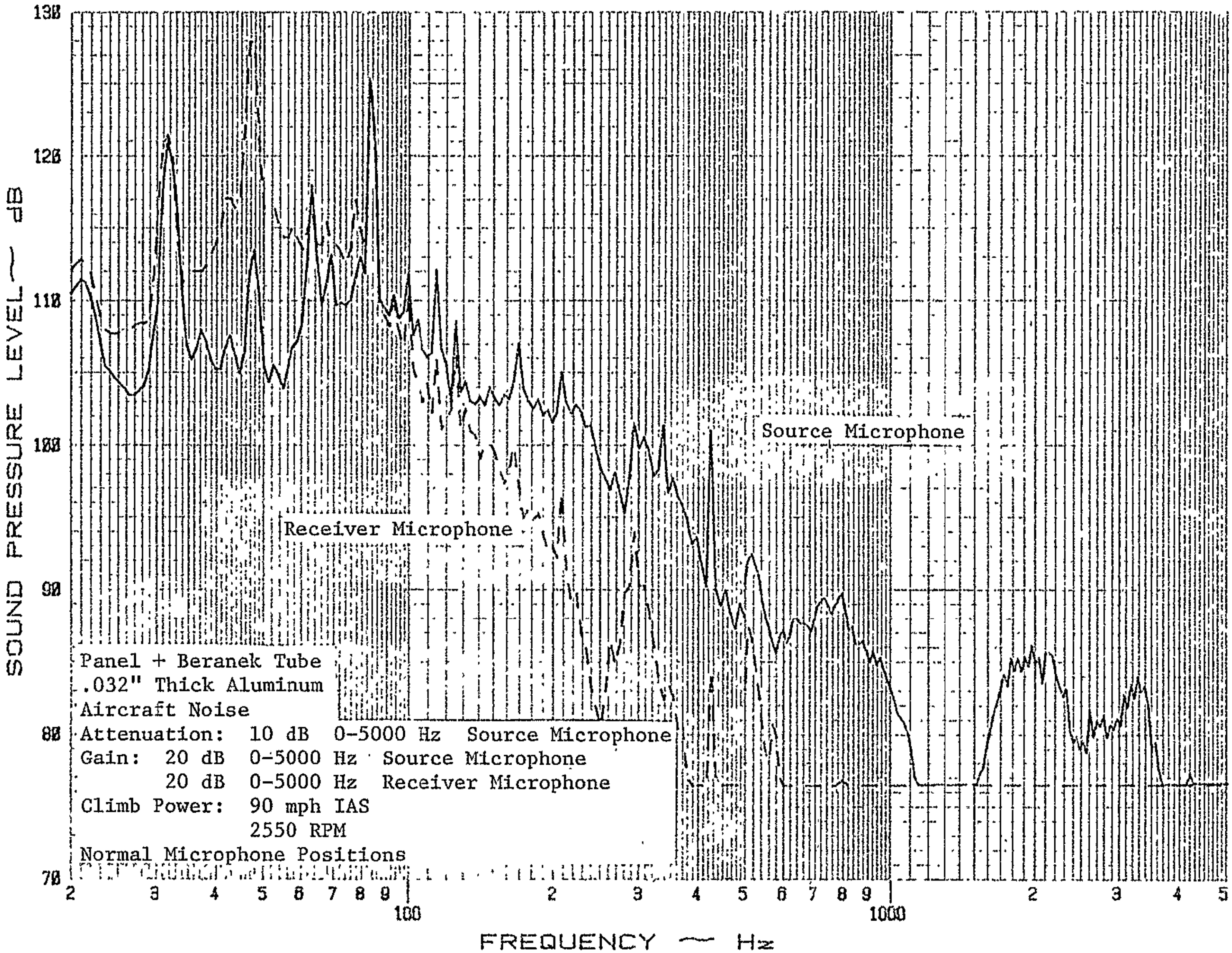

Figure 5: Experimental Sound Pressure Levels Using Recorded Boundary Layer Noise as Sound Source for an Airplane in Climb Conditions.

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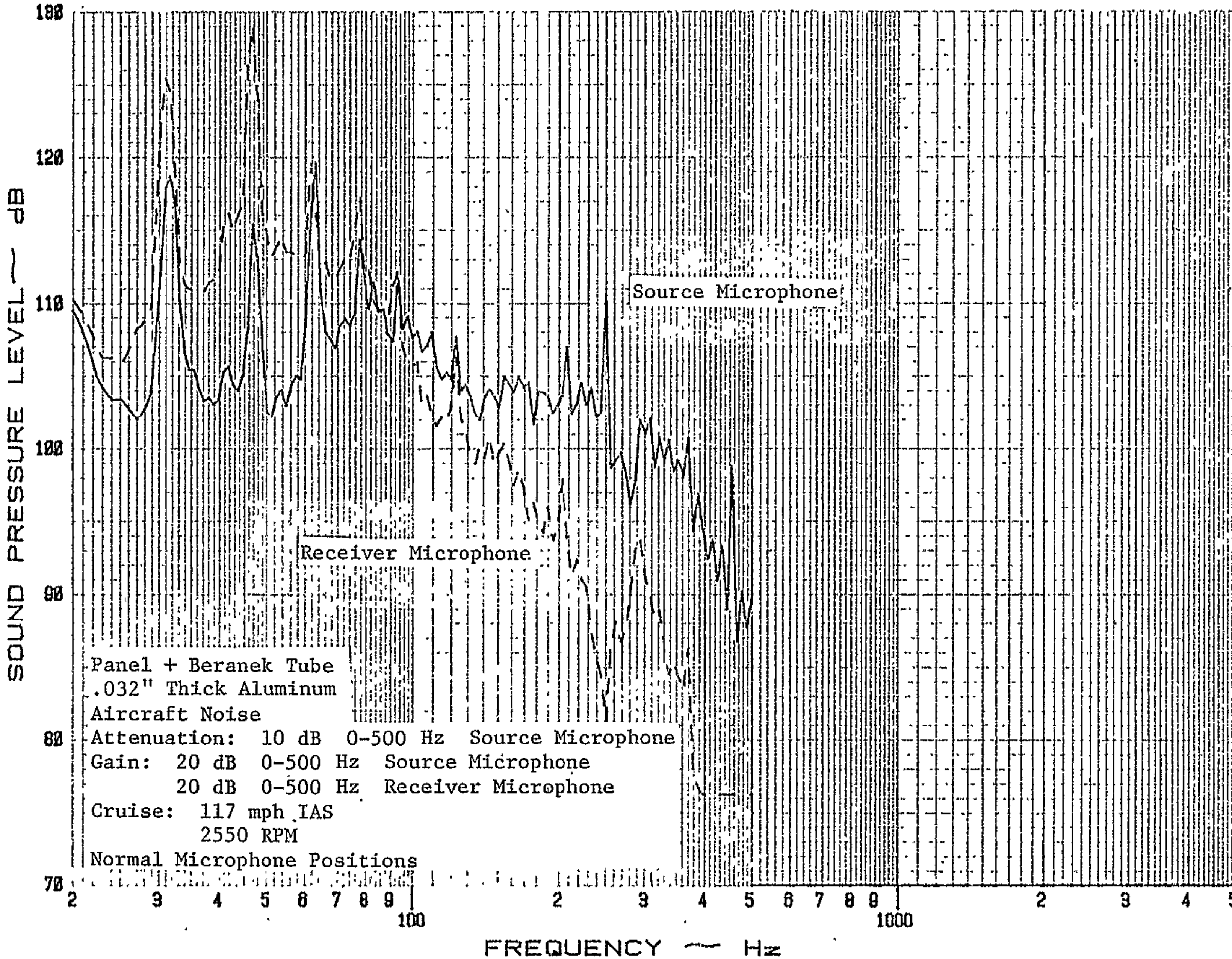

Figure 6: Experimental Sound Pressure Levels Using Recorded Boundary Layer Noise as Sound Source for an Airplane in Cruise Conditions.

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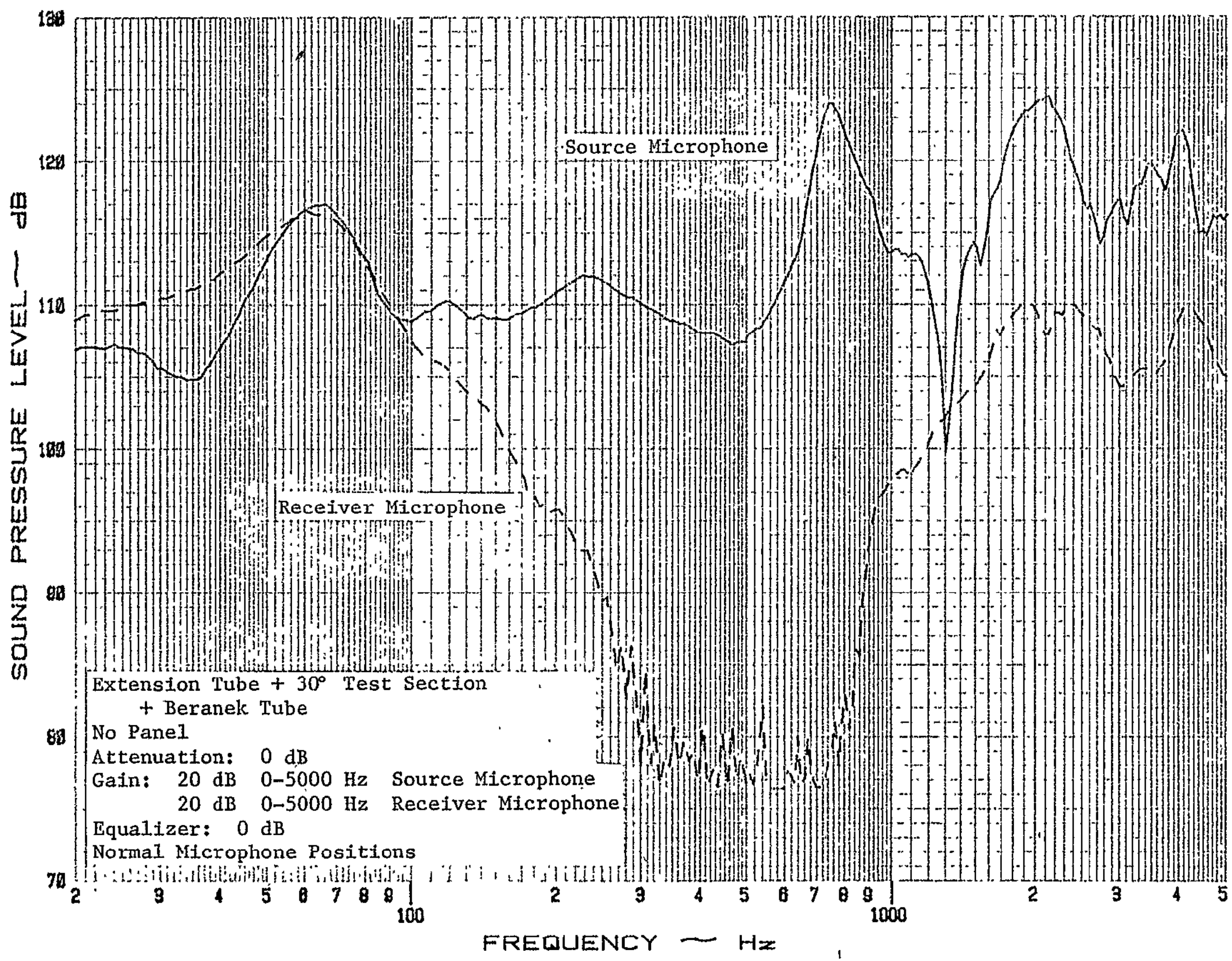

Figure 7: Experimental Sound Pressure Levels for an Equalizer Setting of 0 dB.

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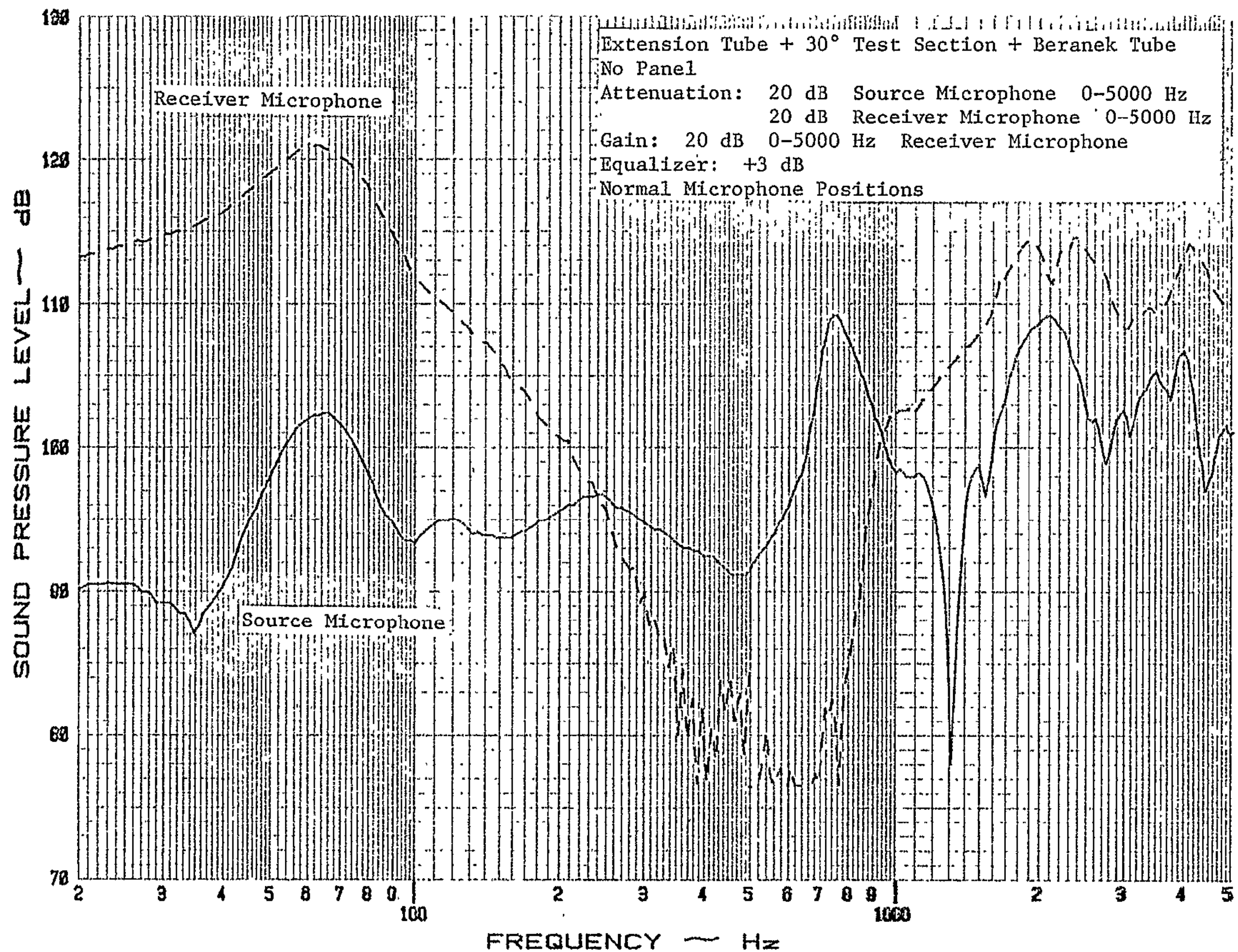

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Figure 8: Experimental Sound Pressure Levels for an Equalizer Setting of +3 dB.

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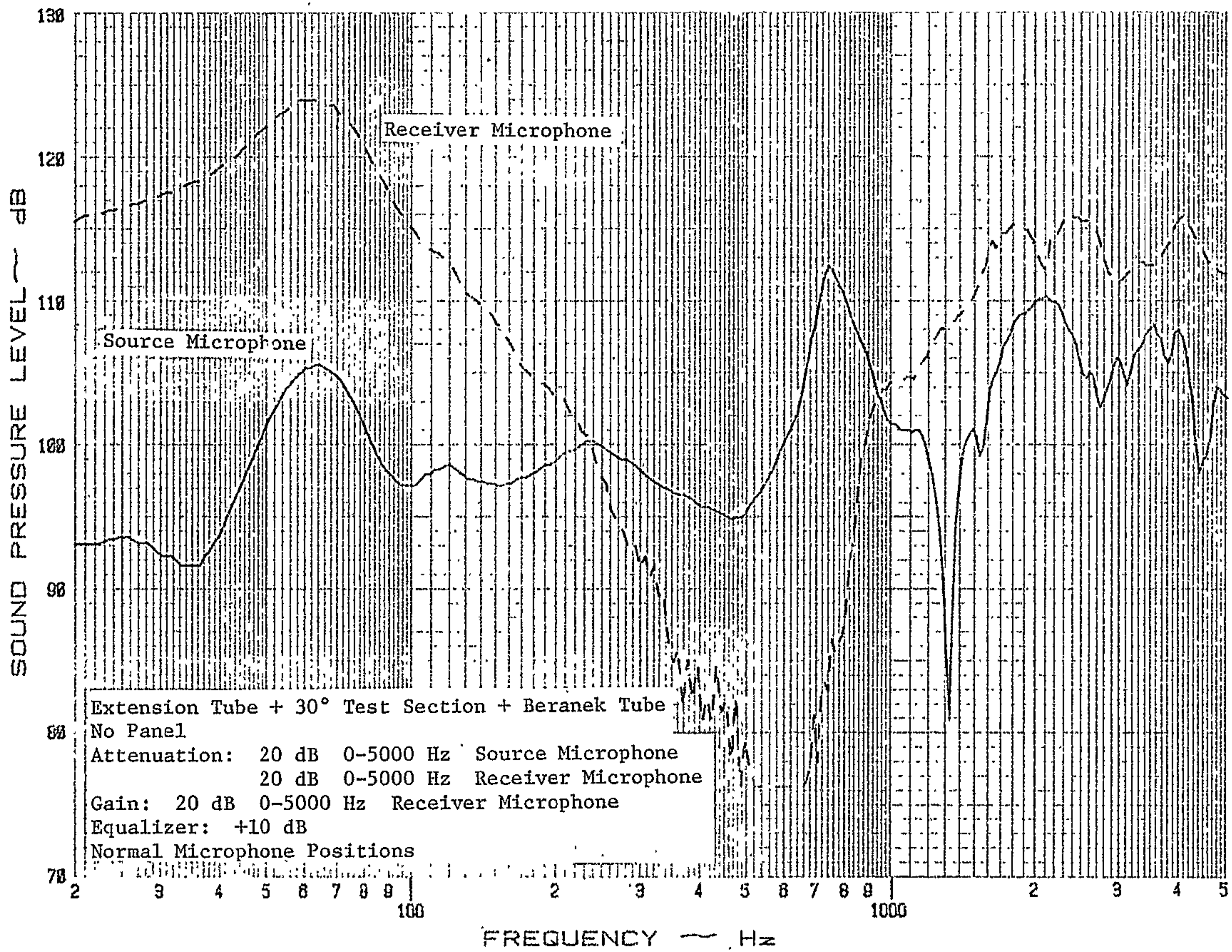

Figure 9: Experimental Sound Pressure Levels for an Equalizer Setting of +10 dB.

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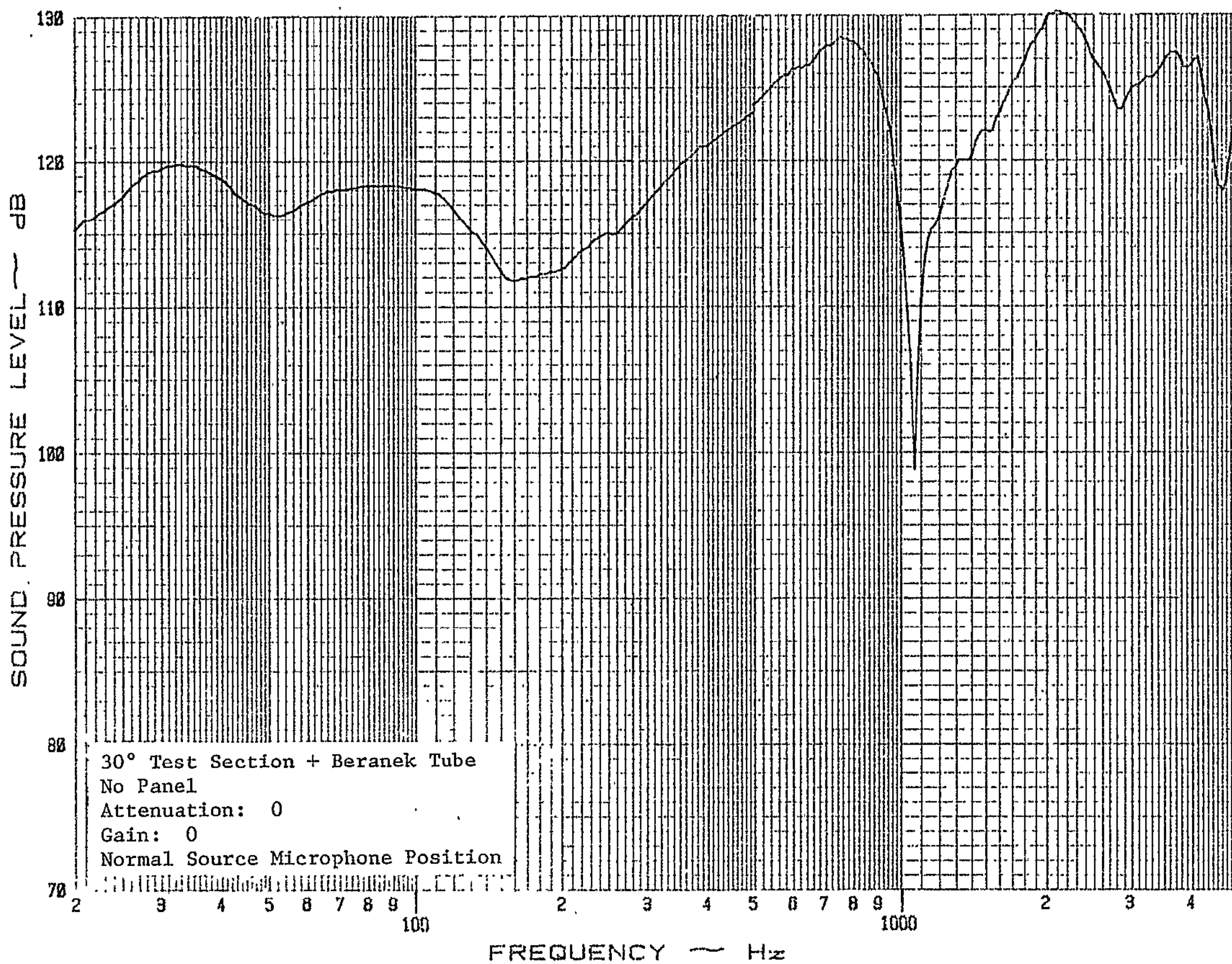

Figure 10: Experimental Sound Pressure Level for the Normal Source Microphone Position.

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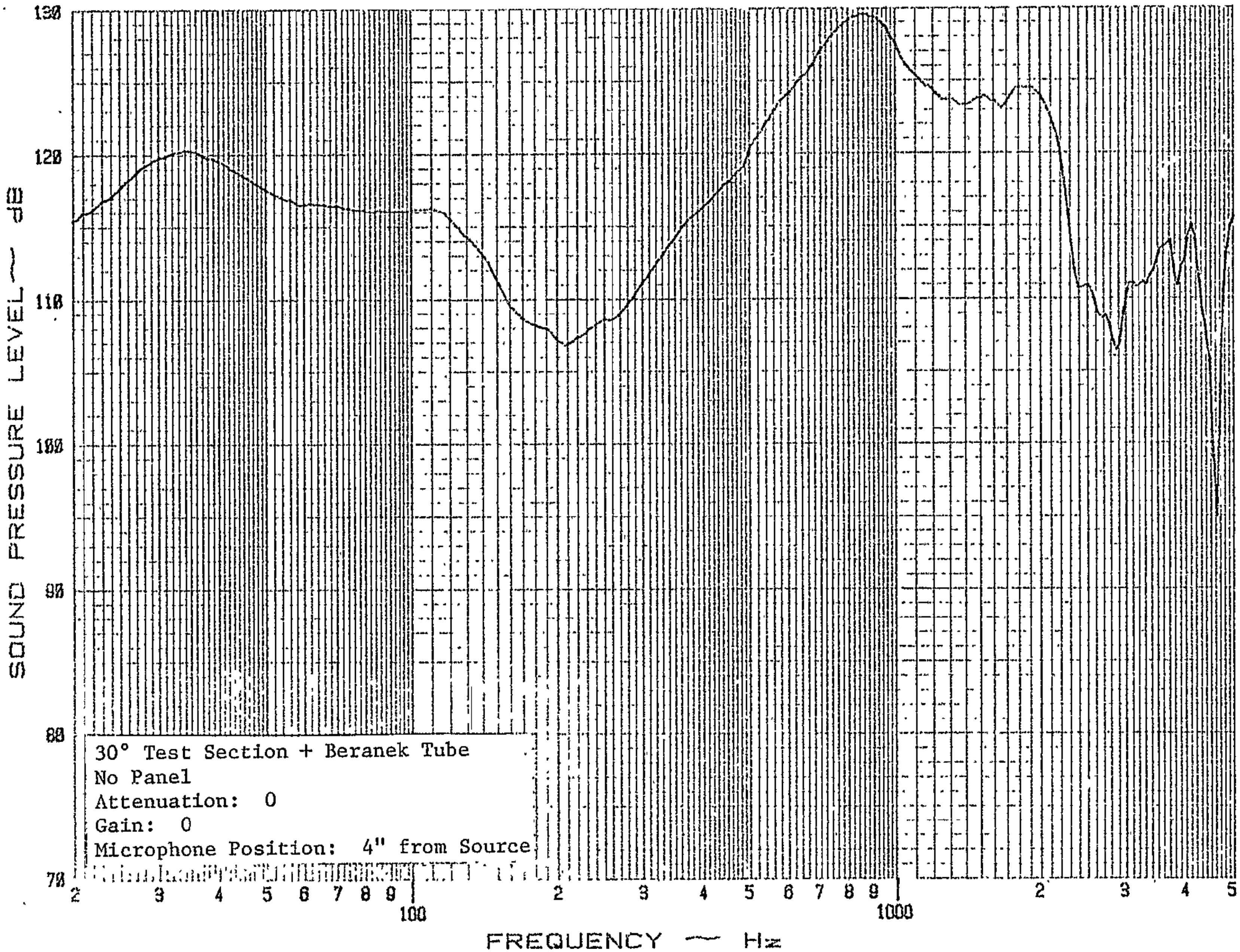

Figure 11: Experimental Sound Pressure Level for a Microphone Position at a Distance of 4" from the Speaker Baffle.

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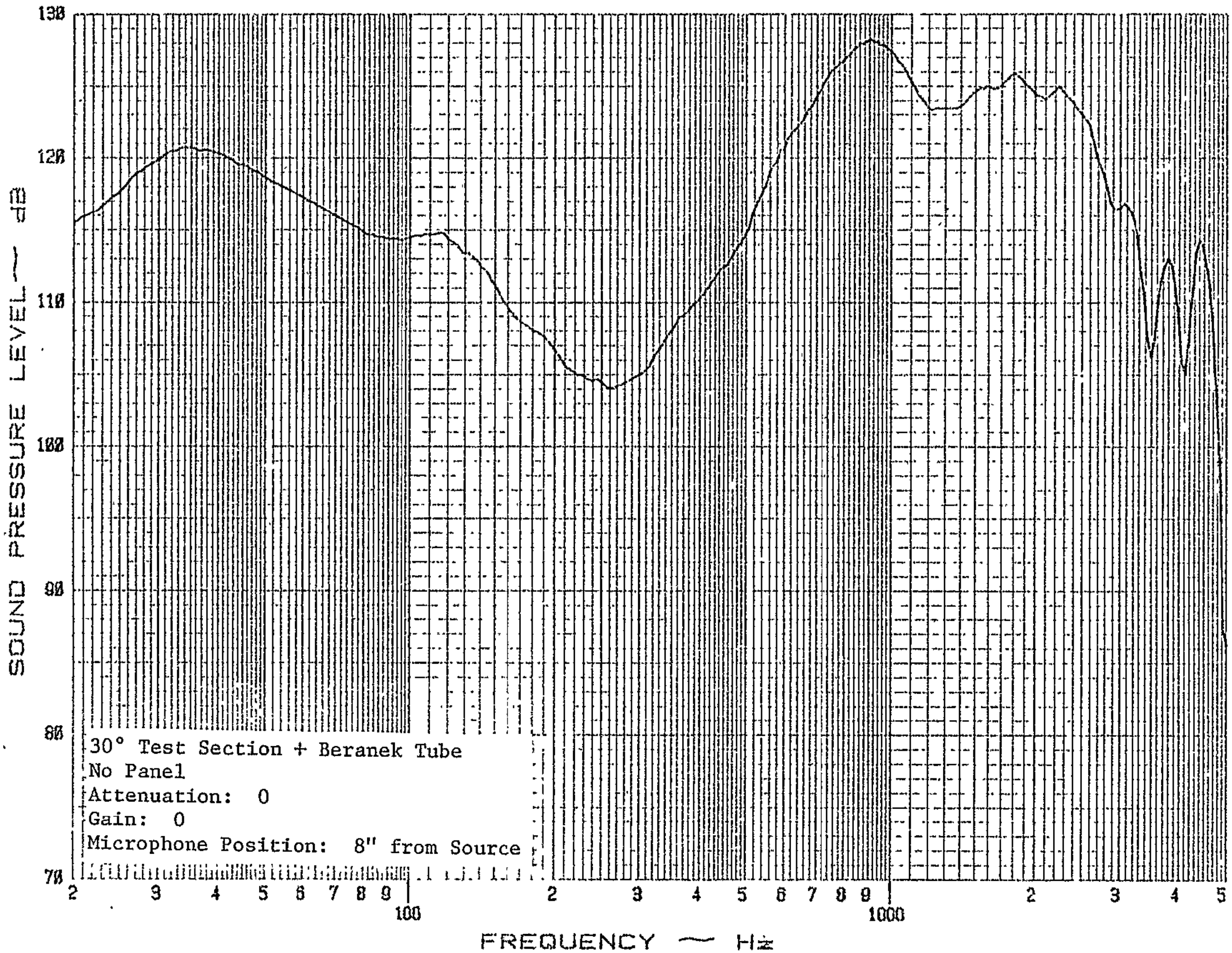

Figure 12: Experimental Sound Pressure Level for a Microphone Position at a Distance of 8" from the Speaker Baffle.

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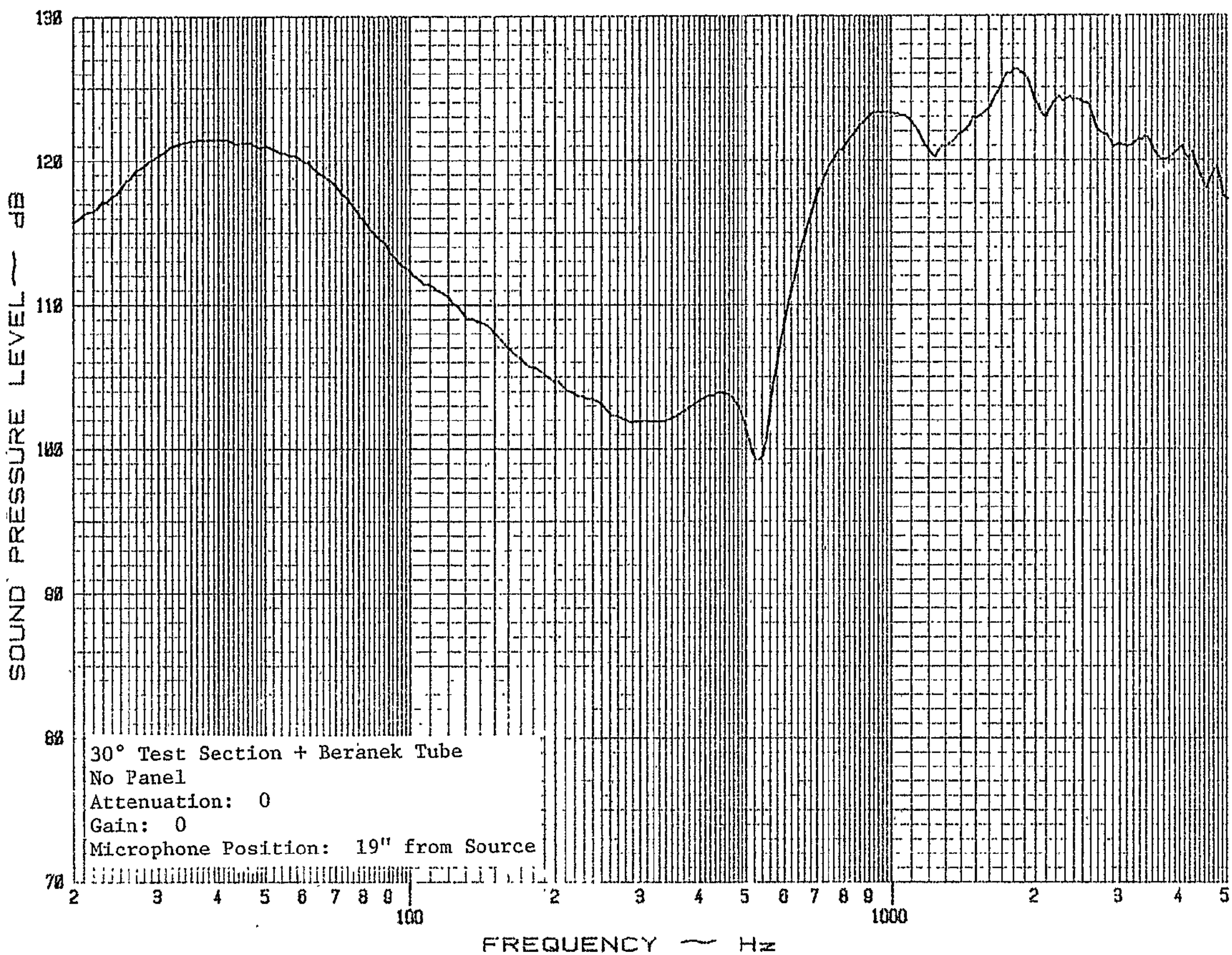

Figure 13: Experimental Sound Pressure Level for a Microphone Position at a Distance of 19" from the Speaker Baffle.

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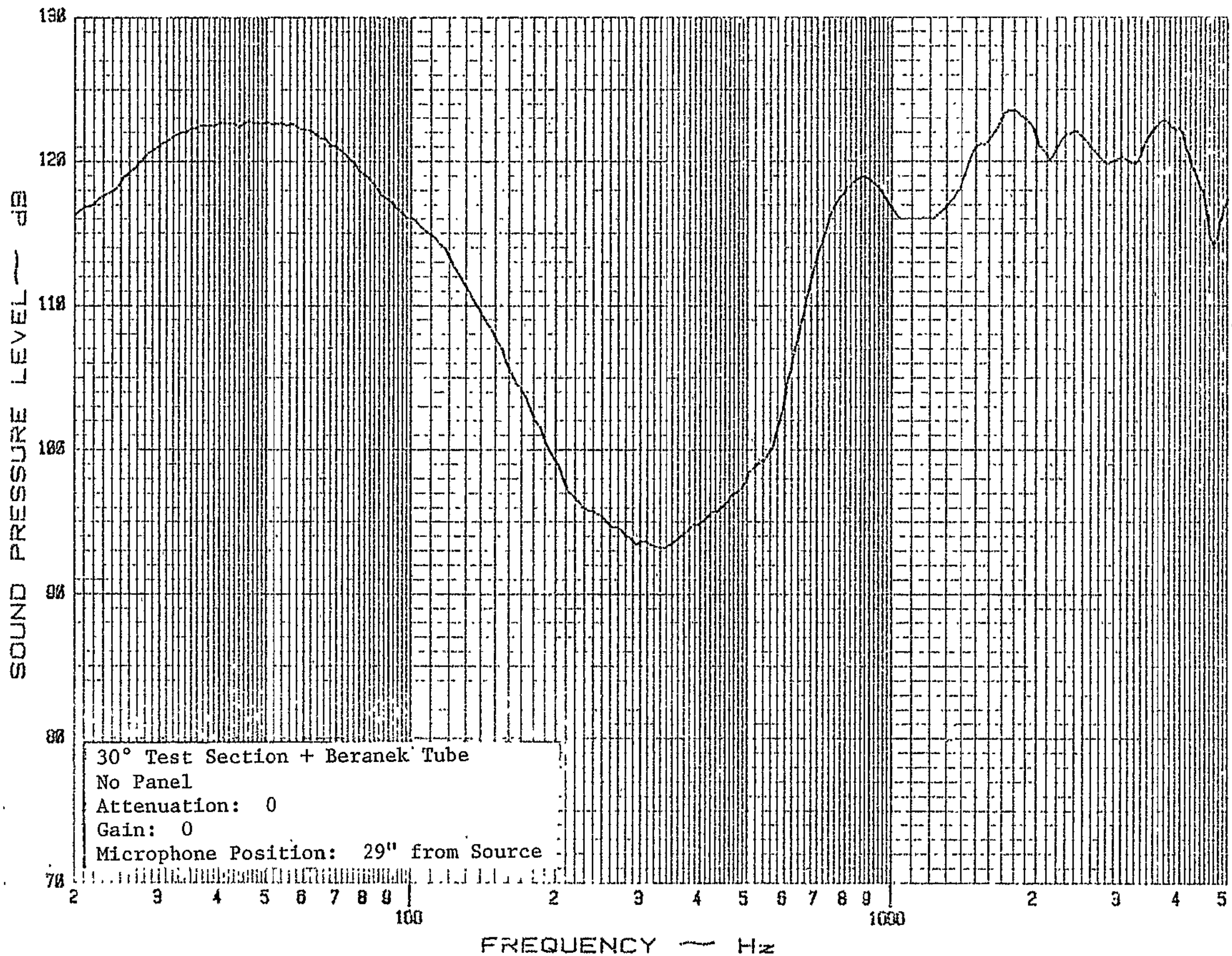

Figure 14: Experimental Sound Pressure Level for a Microphone Position at a Distance of 29" from the Speaker Baffle.

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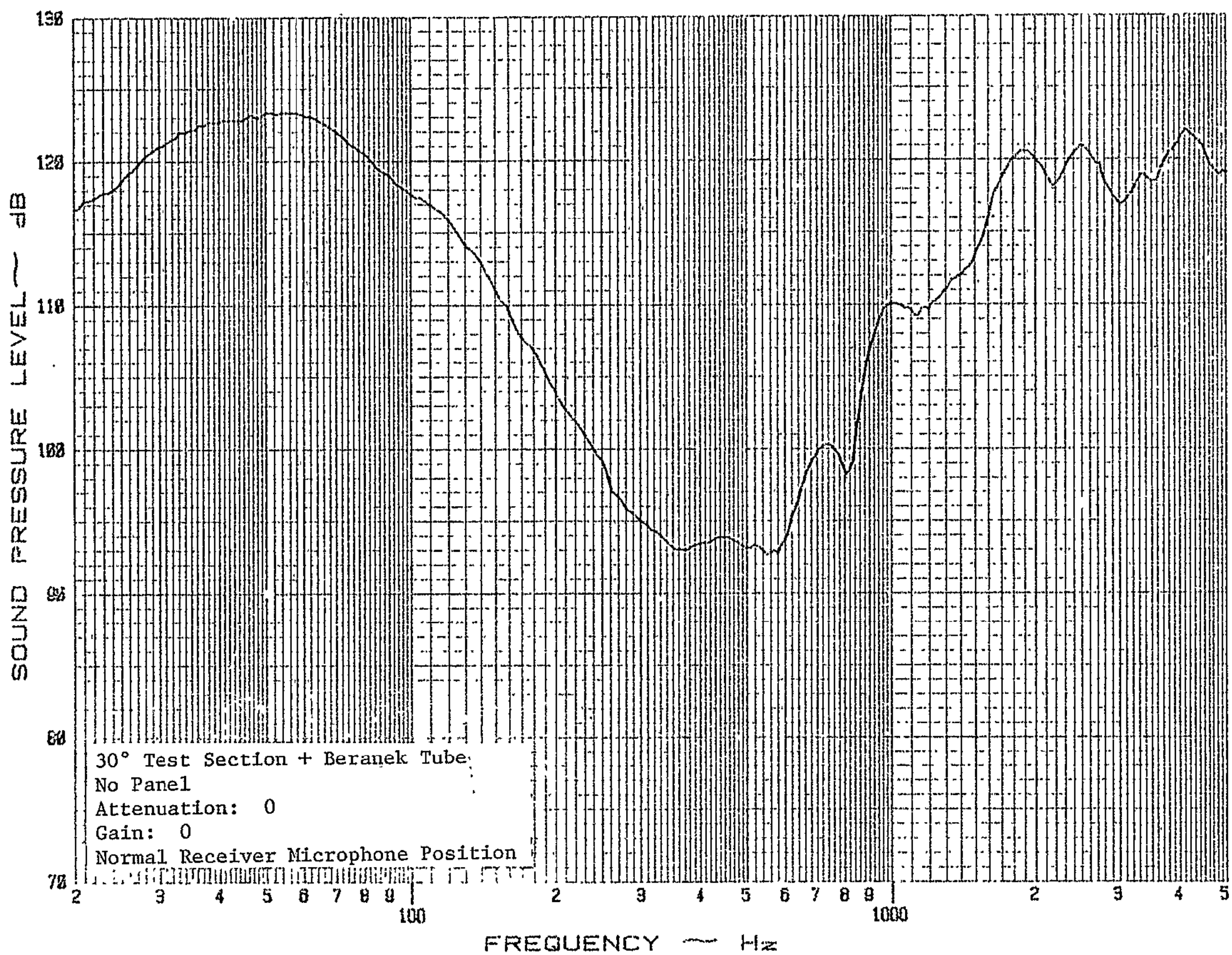

Figure 15: Experimental Sound Pressure Level for the Normal Receiver Microphone Position

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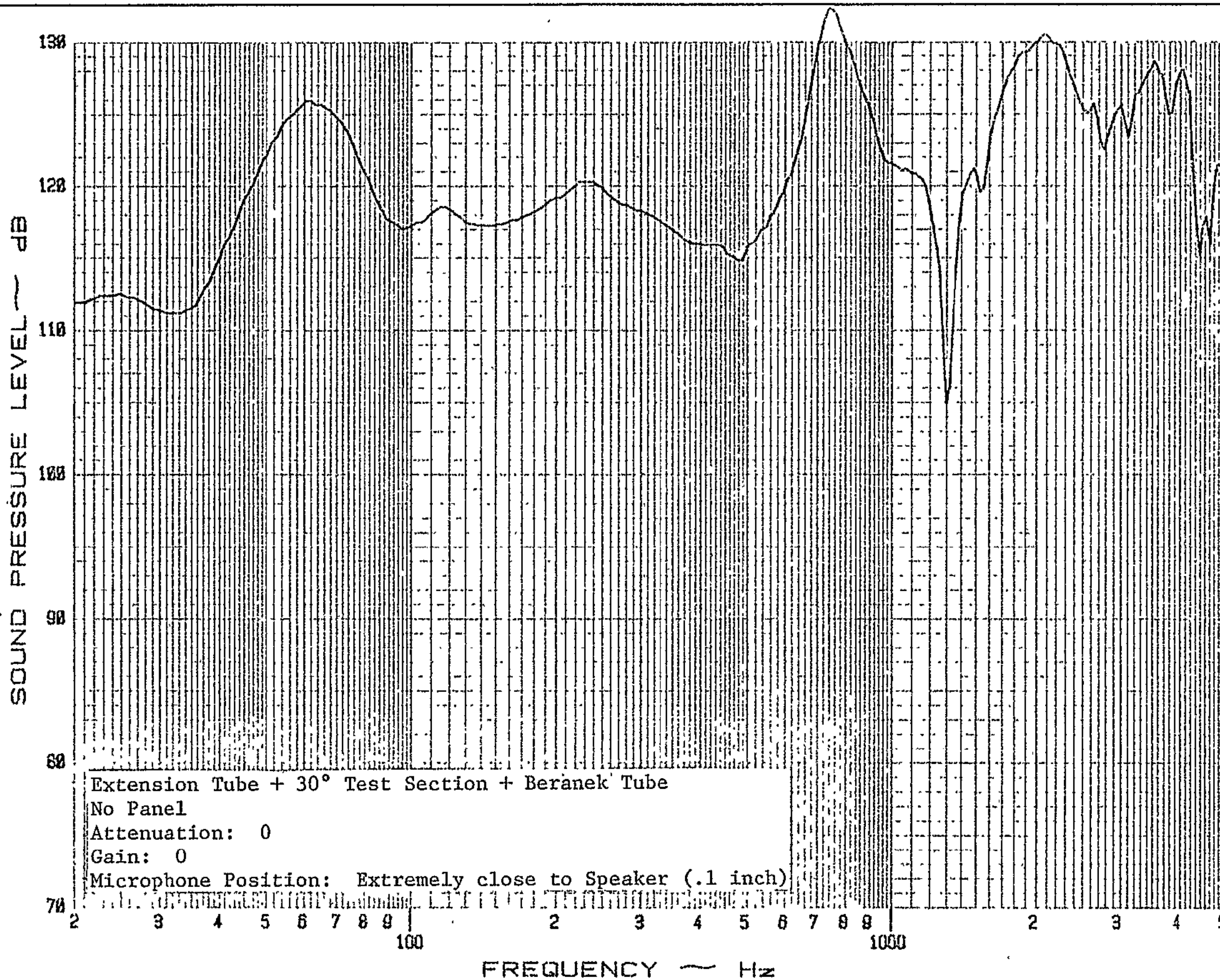

Figure 16: Experimental Sound Pressure Level with the Microphone Extremely Close to the Center Speaker

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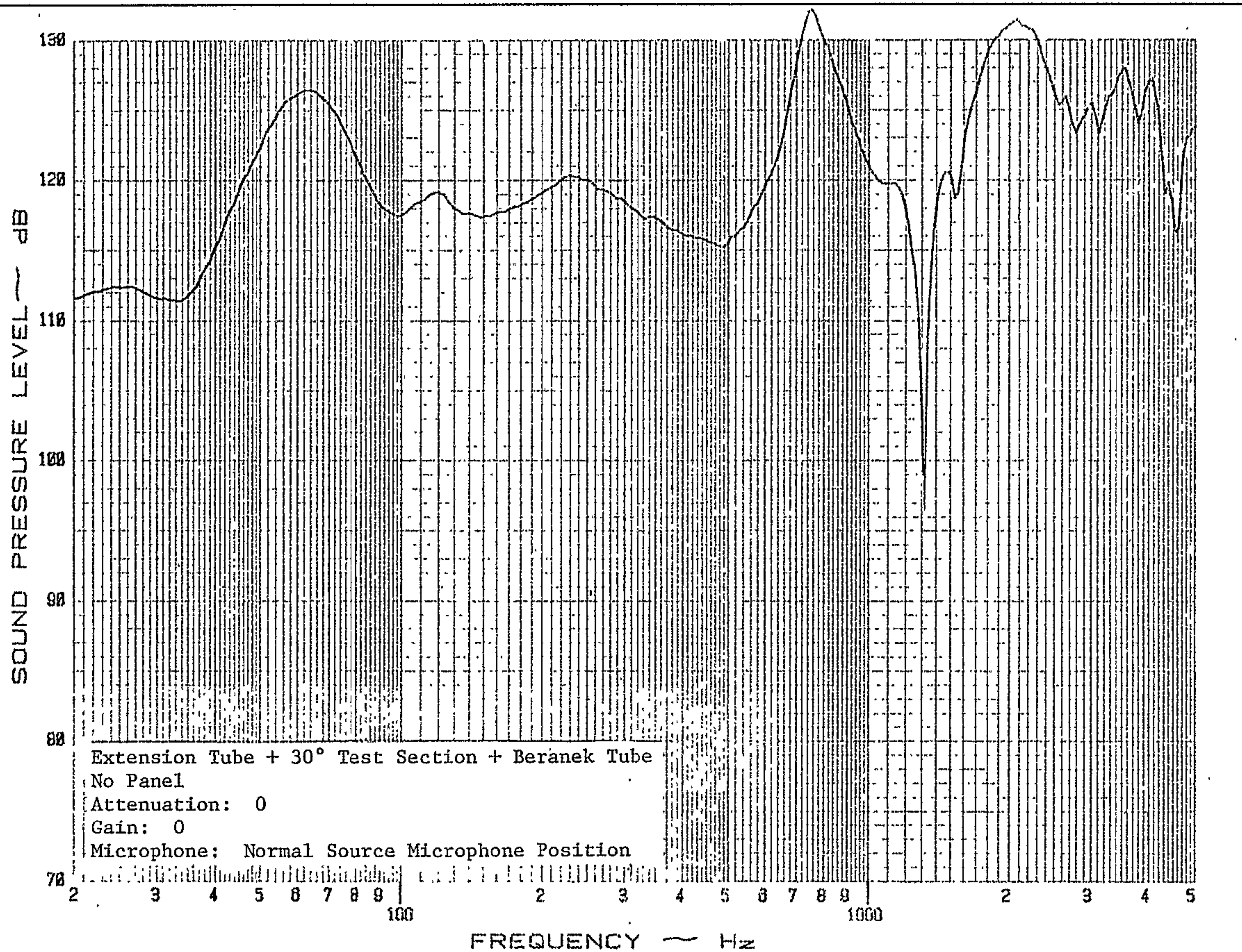

Figure 17: Experimental Sound Pressure Level for the Normal Source Microphone Position.

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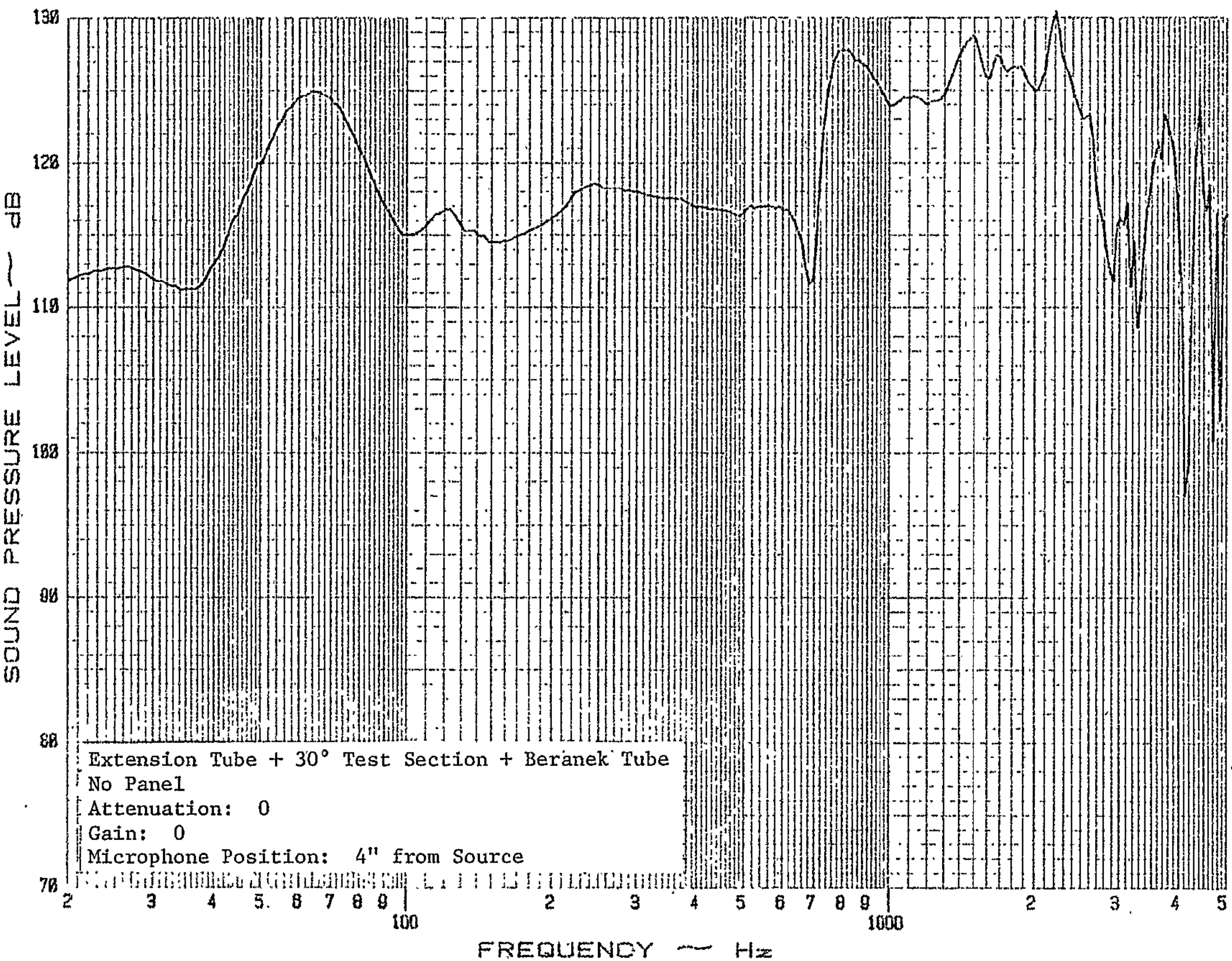

Figure 18: Experimental Sound Pressure Level for a Microphone Position at a Distance of 4" from the Speaker Baffle.

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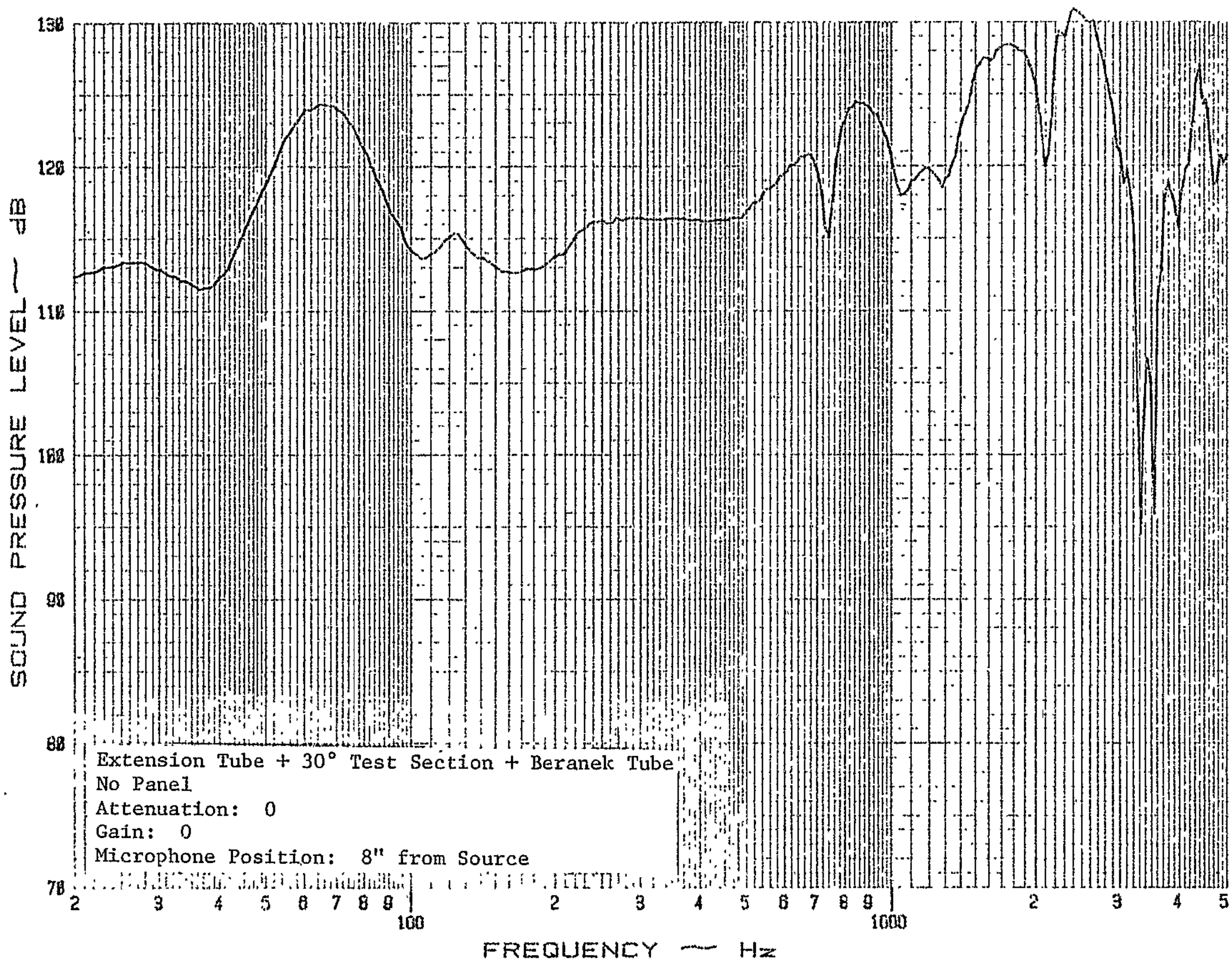

Figure 19: Experimental Sound Pressure Level for a Microphone Position at a Distance of 8" from the Speaker Baffle.

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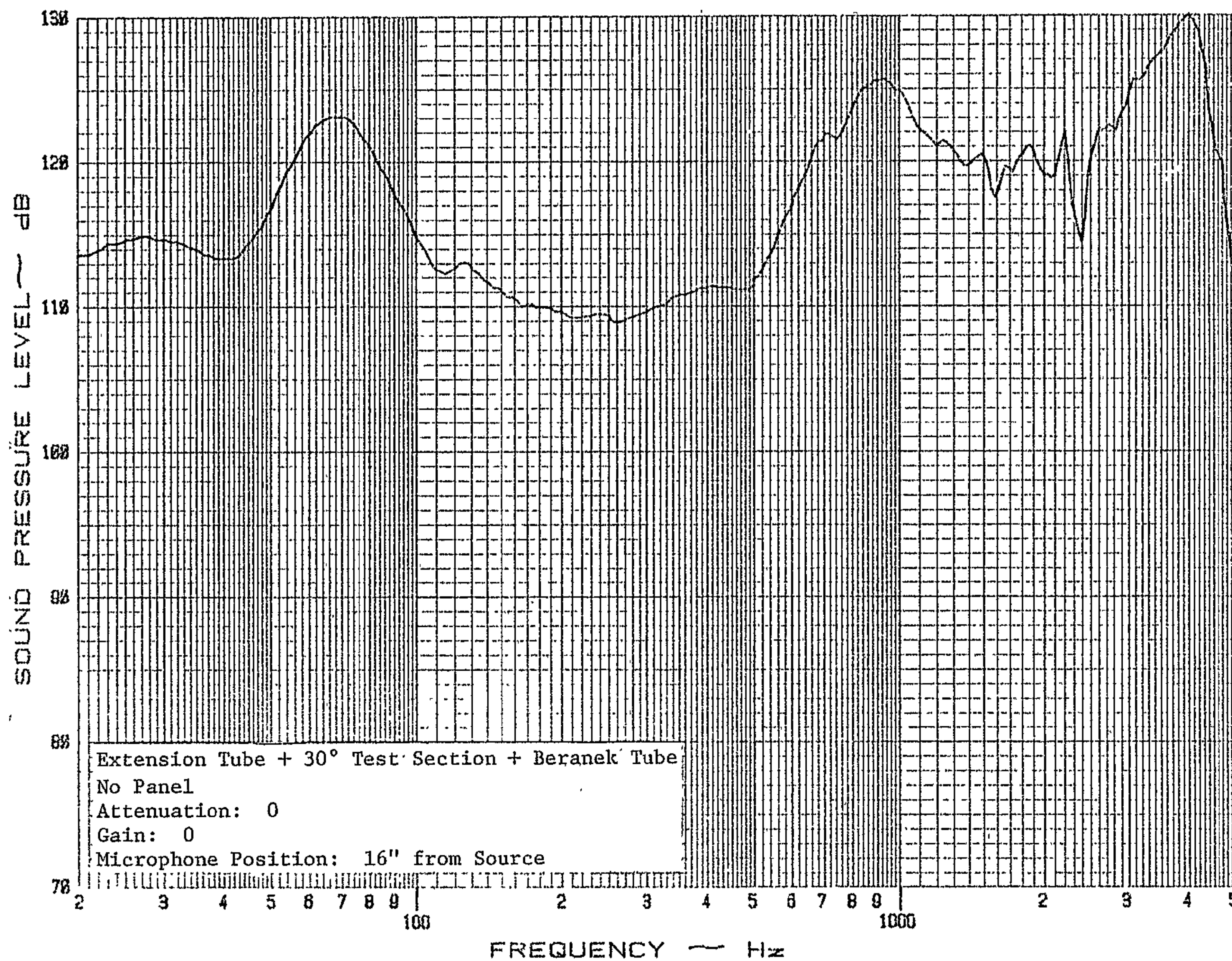

Figure 20: Experimental Sound Pressure Level for a Microphone Position at a Distance of 16" from the Speaker Baffle.

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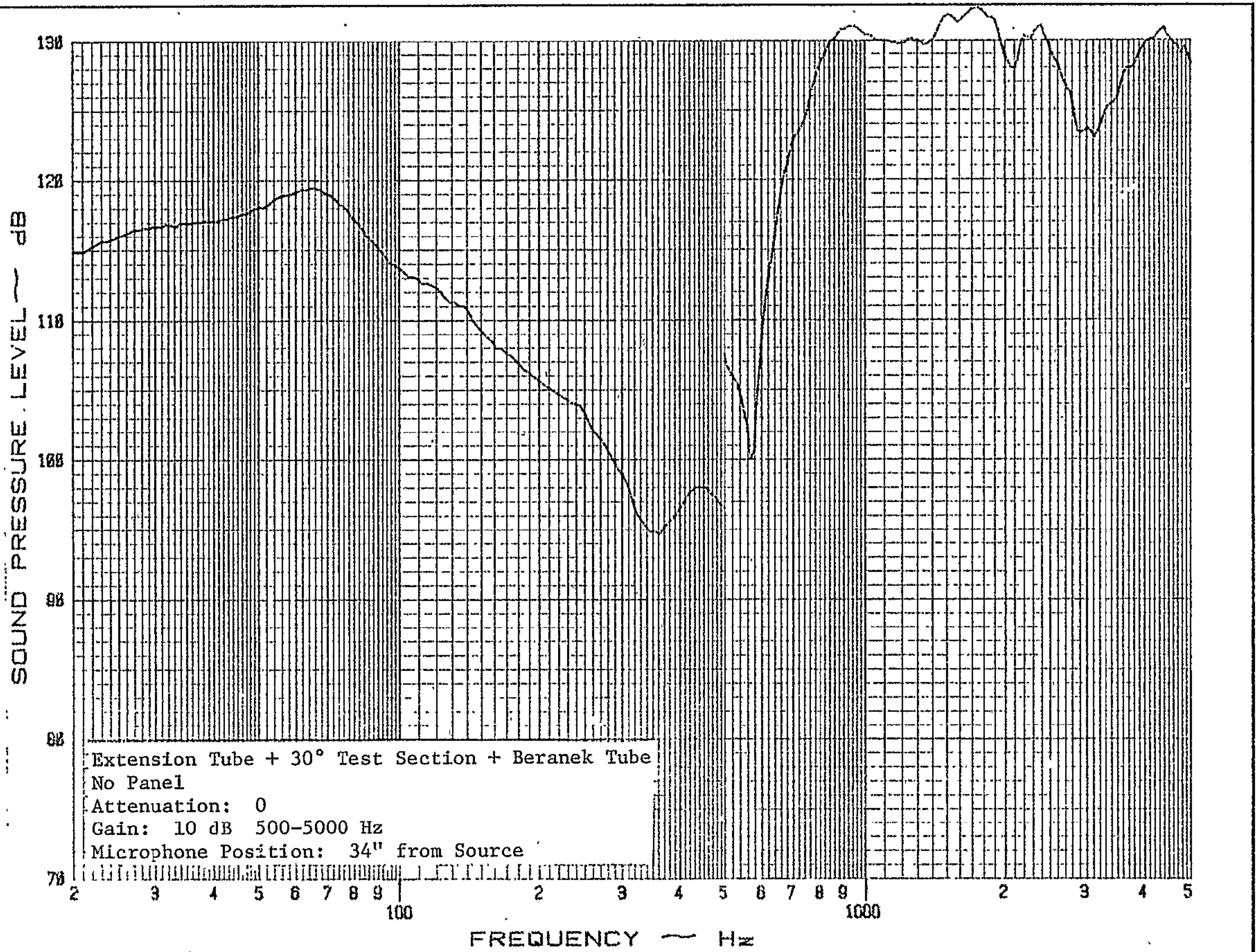

Figure 21: Experimental Sound Pressure Level for a Microphone Position at a Distance of 34" from the Speaker Baffle.

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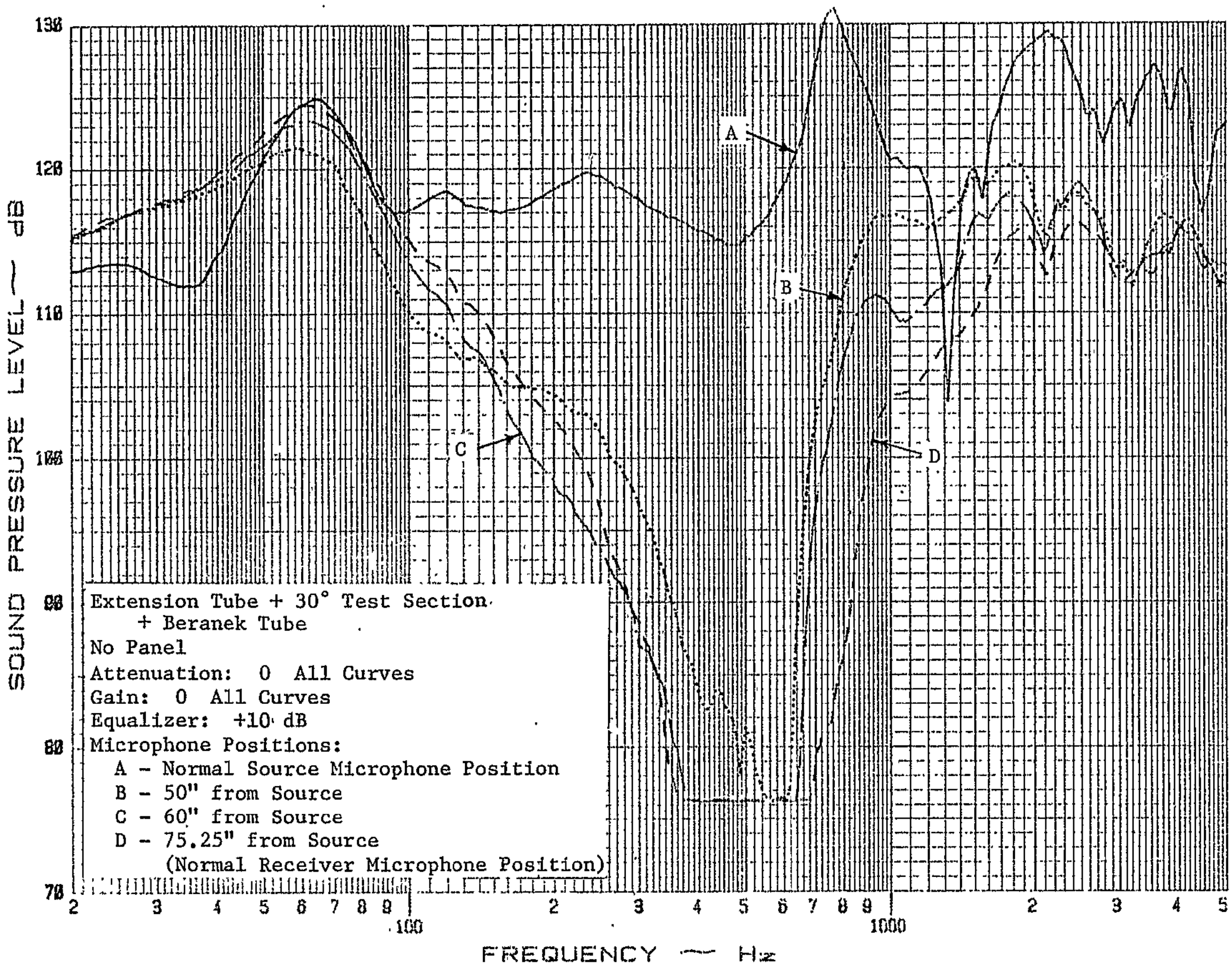

Figure 22: Experimental Sound Pressure Levels for Various Microphone Positions

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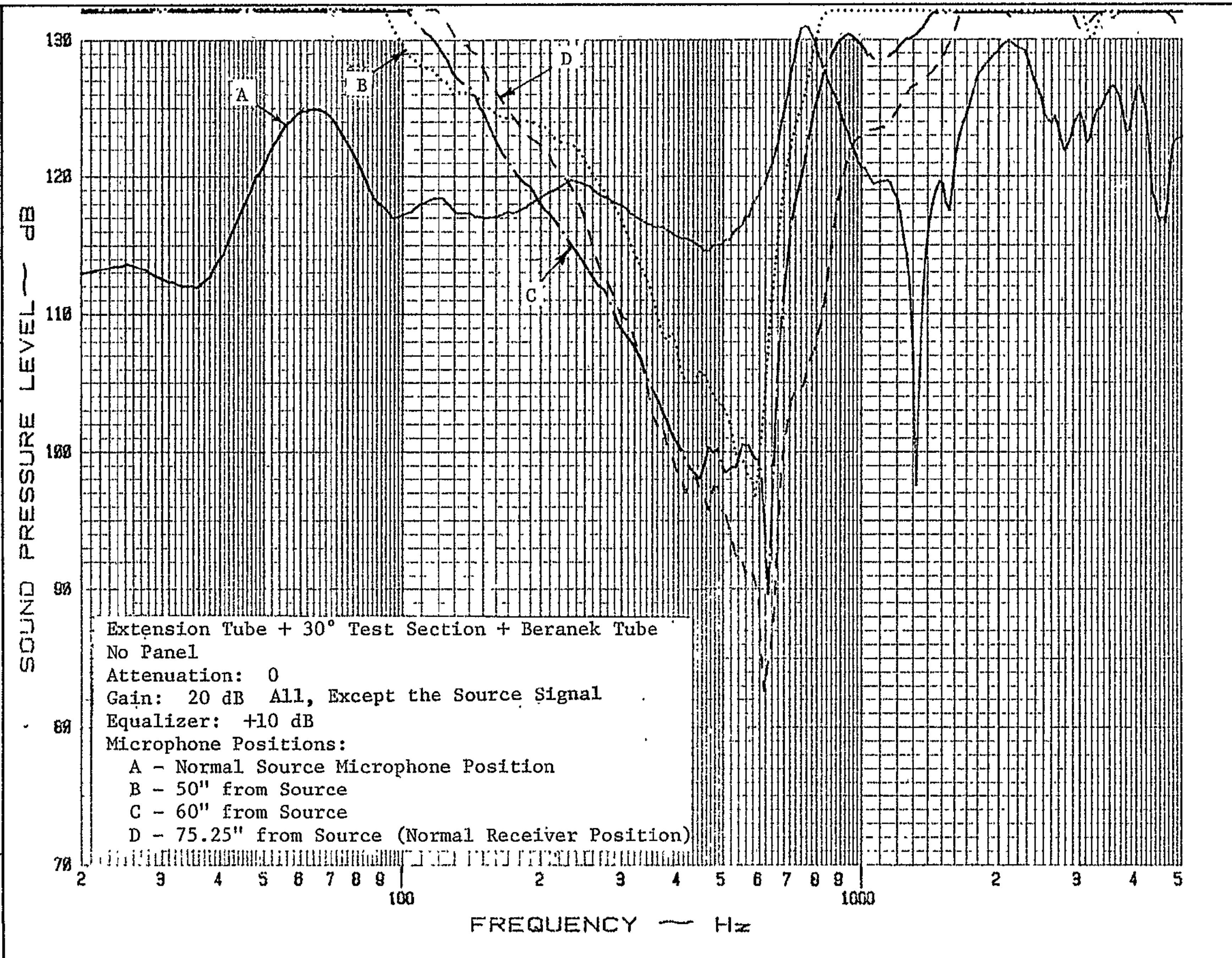

Figure 23: Experimental Sound Pressure Levels for Various Microphone Positions (Gained)

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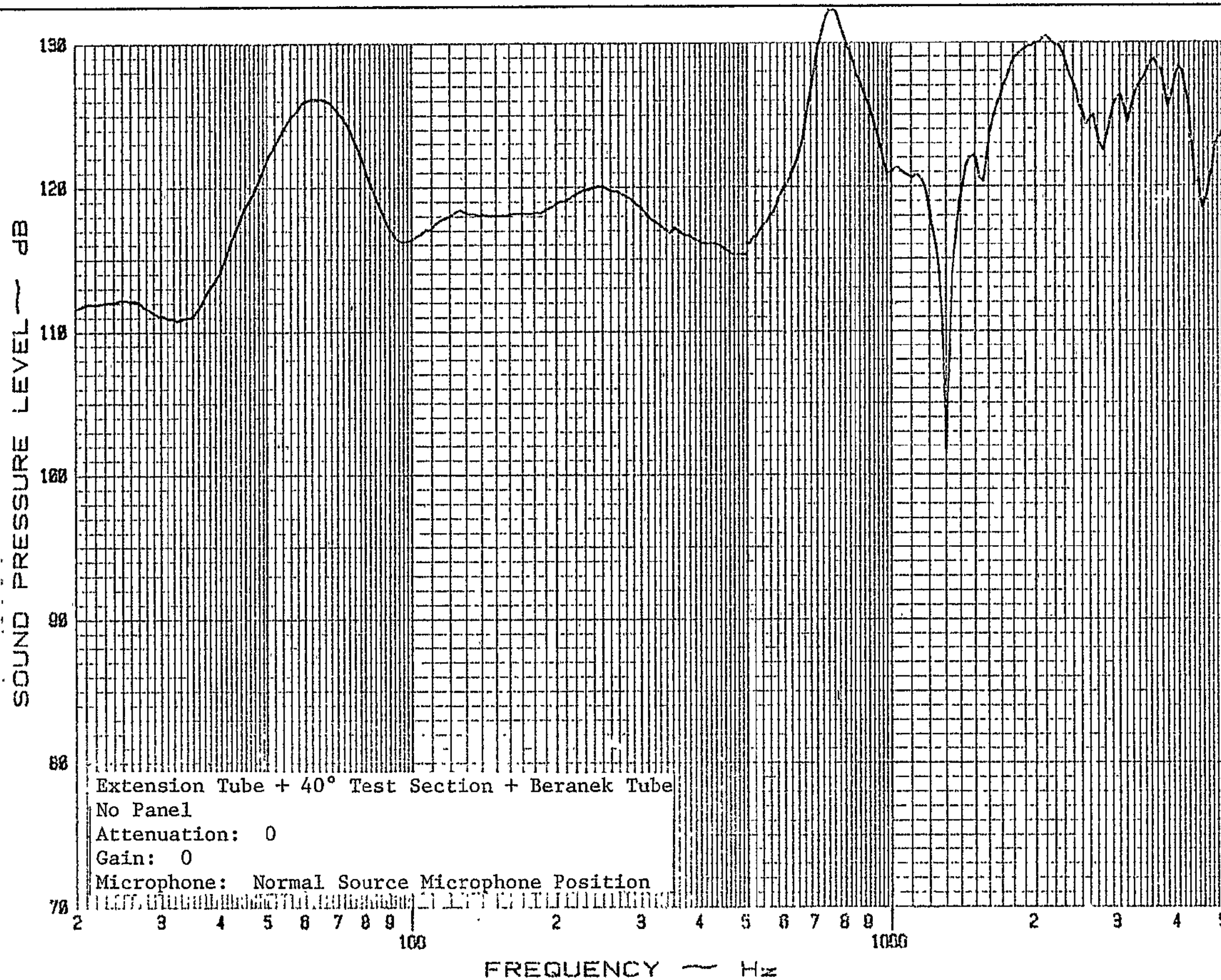

Figure 24: Experimental Sound Pressure Level for Normal Microphone Position Using the 40° Test Section.

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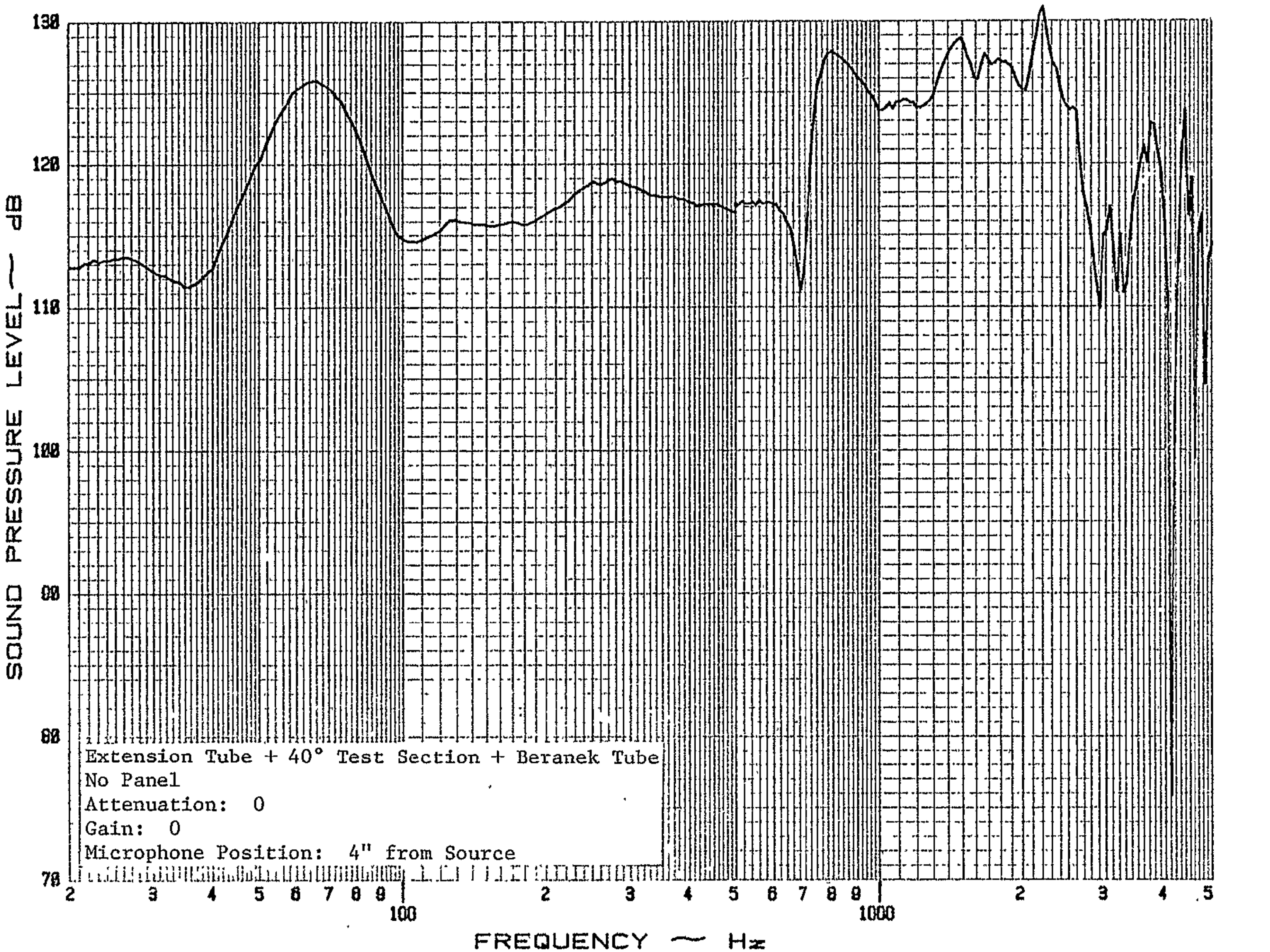

Figure 25: Experimental Sound Pressure Level for a Microphone Position at a Distance of 4" from the Speaker Baffle, Using the 40° Test Section.

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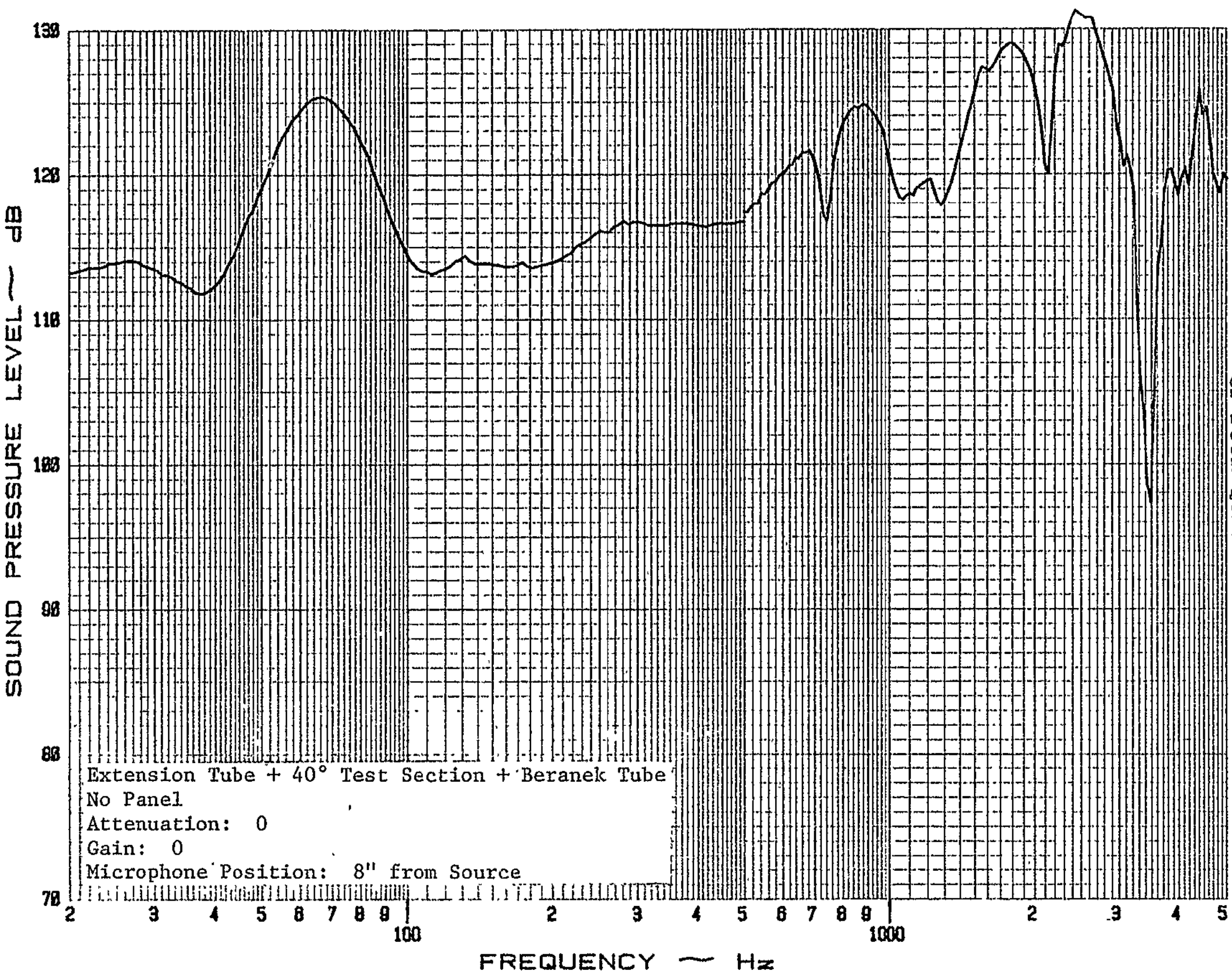

Figure 26: Experimental Sound Pressure Level for a Microphone Position at a Distance of 8" from the Speaker Baffle, Using the 40° Test Section.

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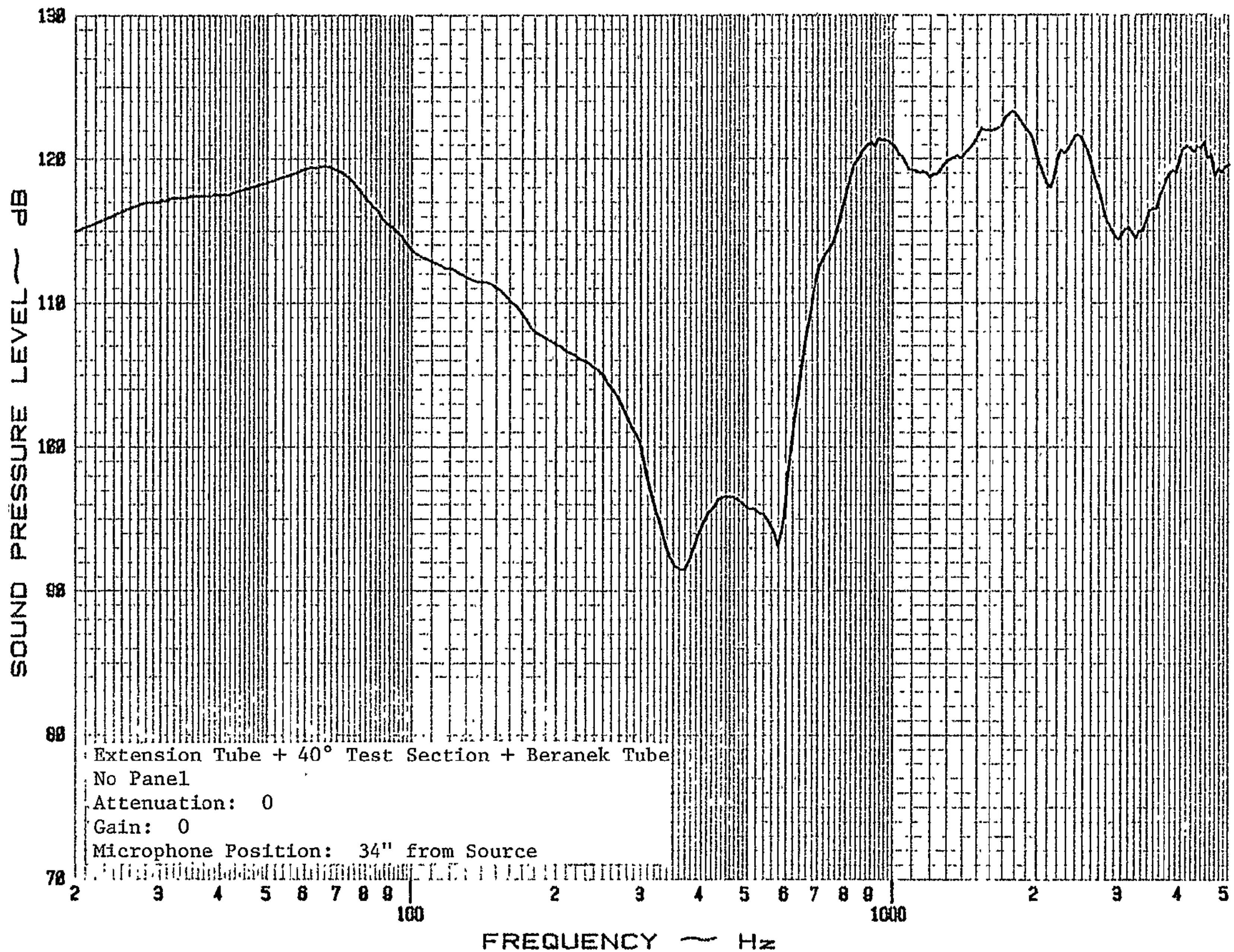

Figure 27: Experimental Sound Pressure Level for a Microphone Position at a Distance of 34" from the Speaker Baffle, Using the 40° Test Section.

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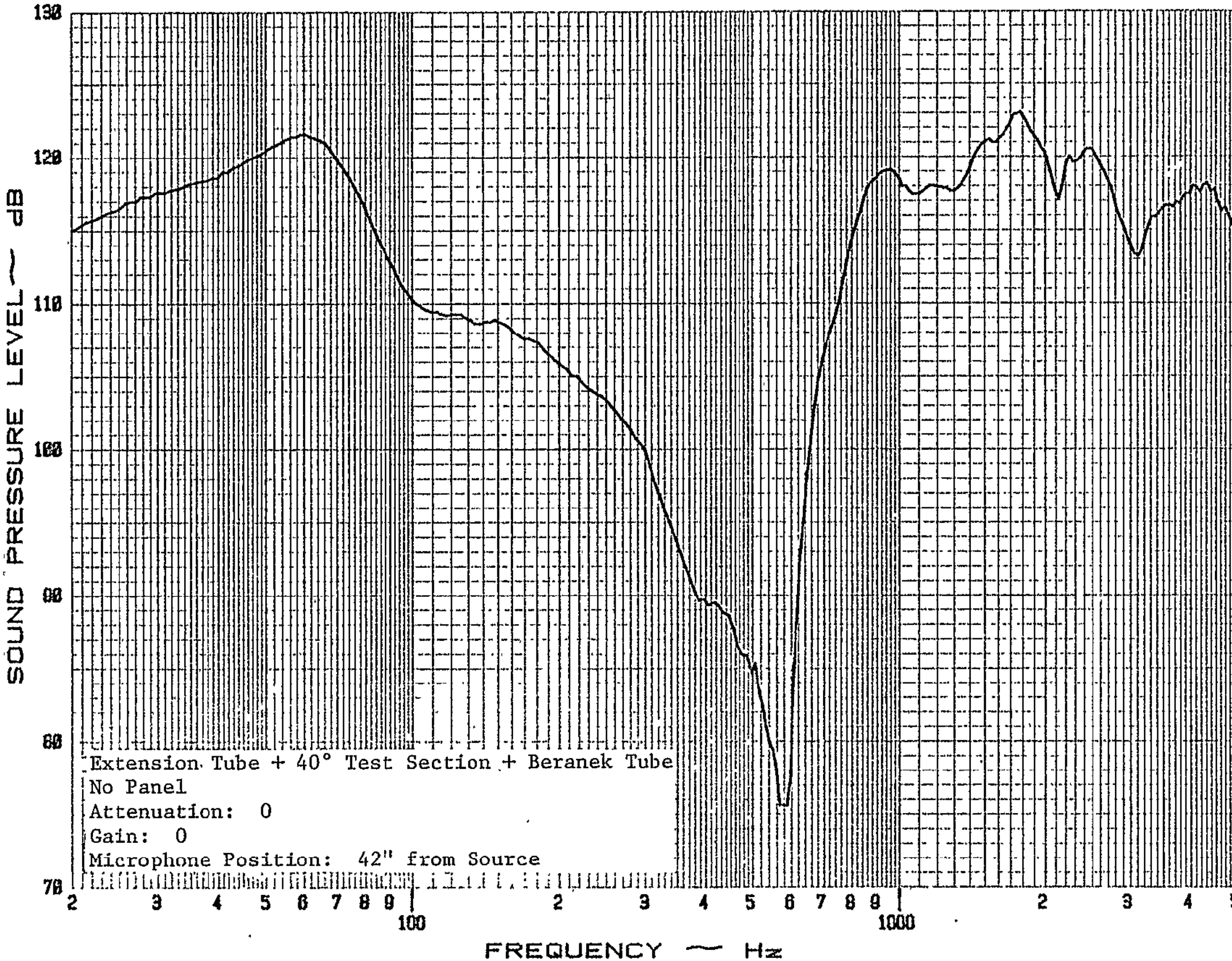

Figure 28: Experimental Sound Pressure Level for a Microphone Position at a Distance of 42" from the Speaker Baffle, Using the 40° Test Section.

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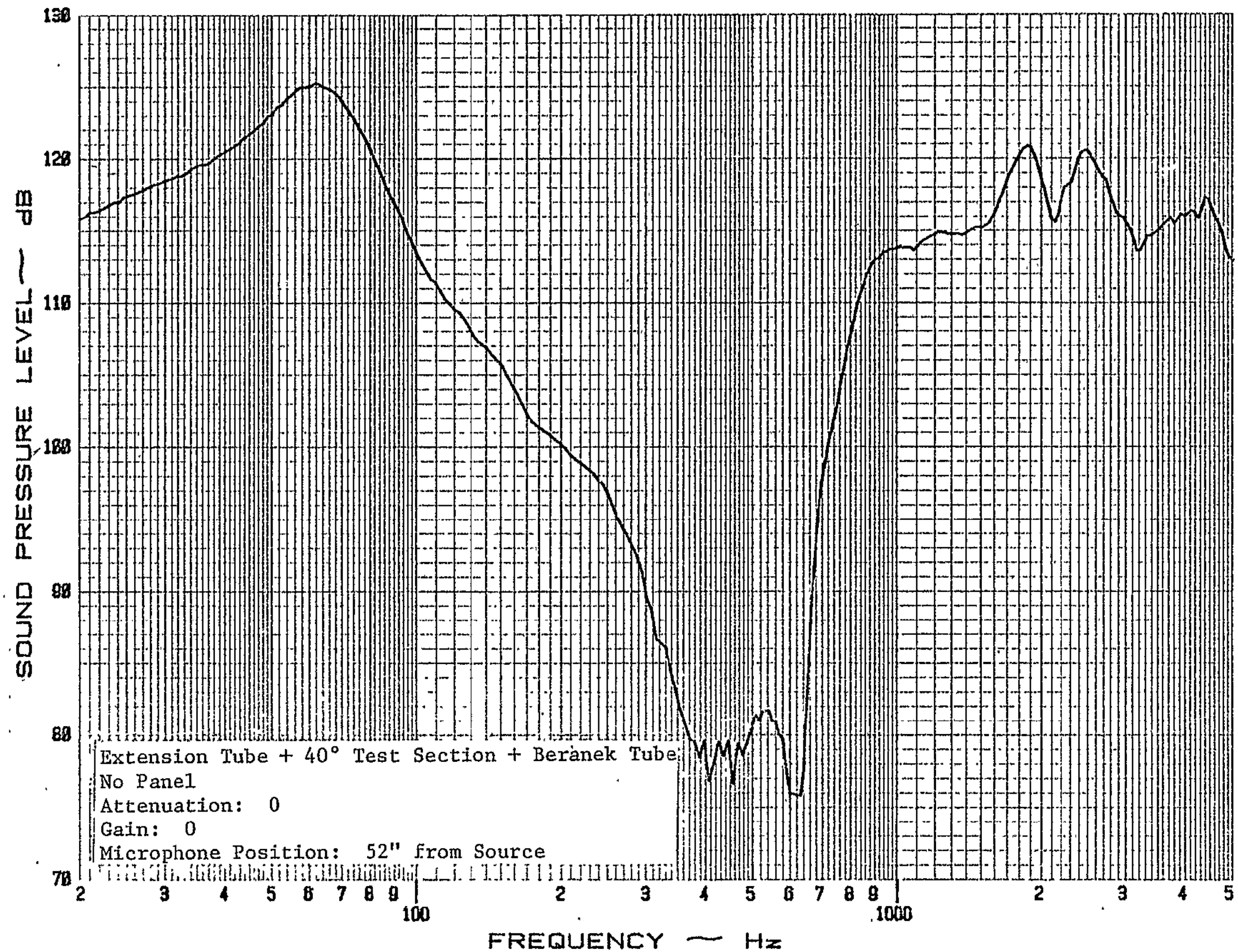

Figure 29: Experimental Sound Pressure Level for a Microphone Position at a Distance of 52" from the Speaker Baffle, Using the 40° Test Section.

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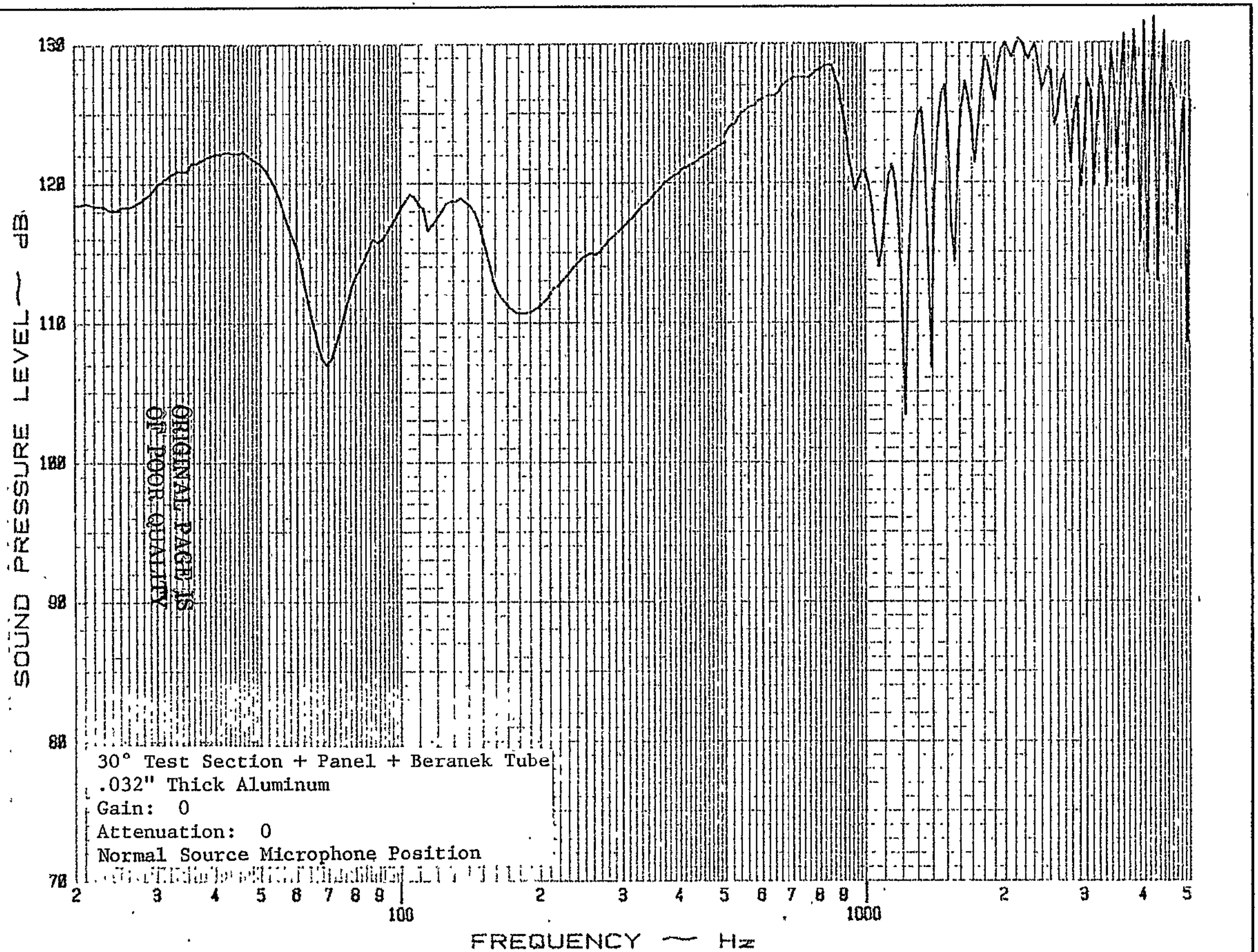

Figure 30: Experimental Sound Pressure Level for the Normal Source Microphone Position with a Test Panel Installed.

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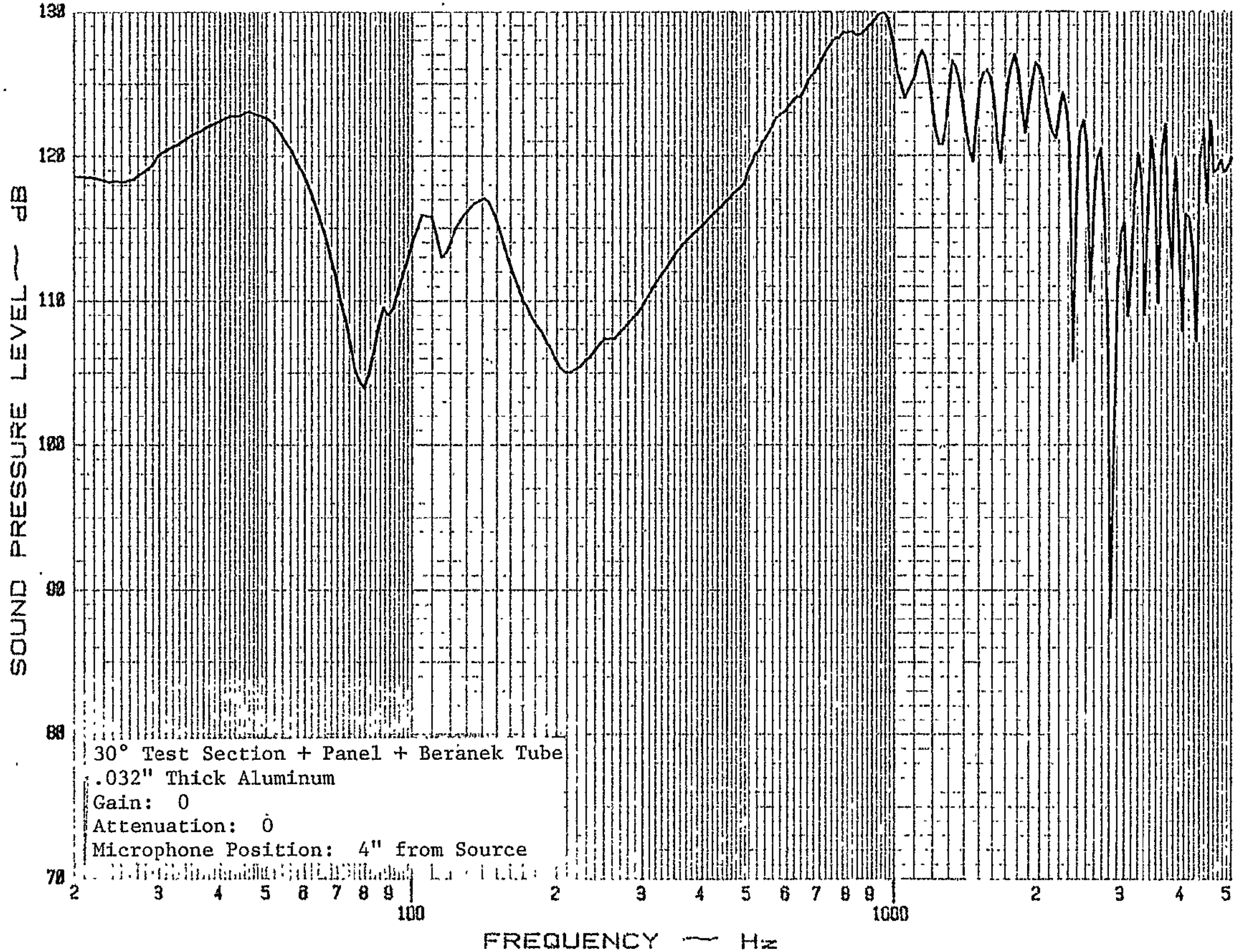

Figure 31: Experimental Sound Pressure Level for a Microphone Position at a Distance of 4" from the Speaker Baffle with a Test Panel Installed.

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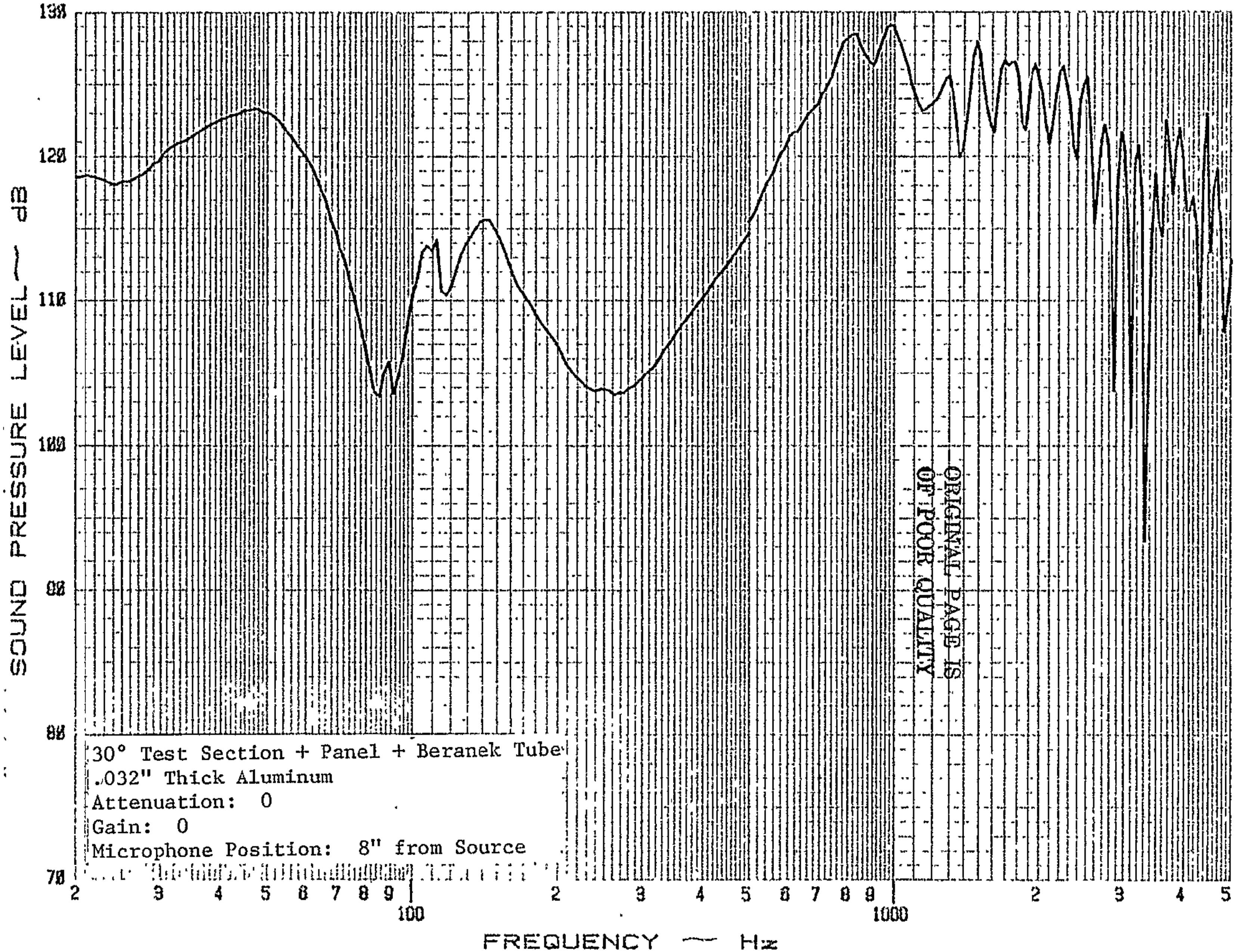

Figure 32: Experimental Sound Pressure Level for a Microphone Position at a Distance of 8" from the Speaker Baffle with a Test Panel Installed.

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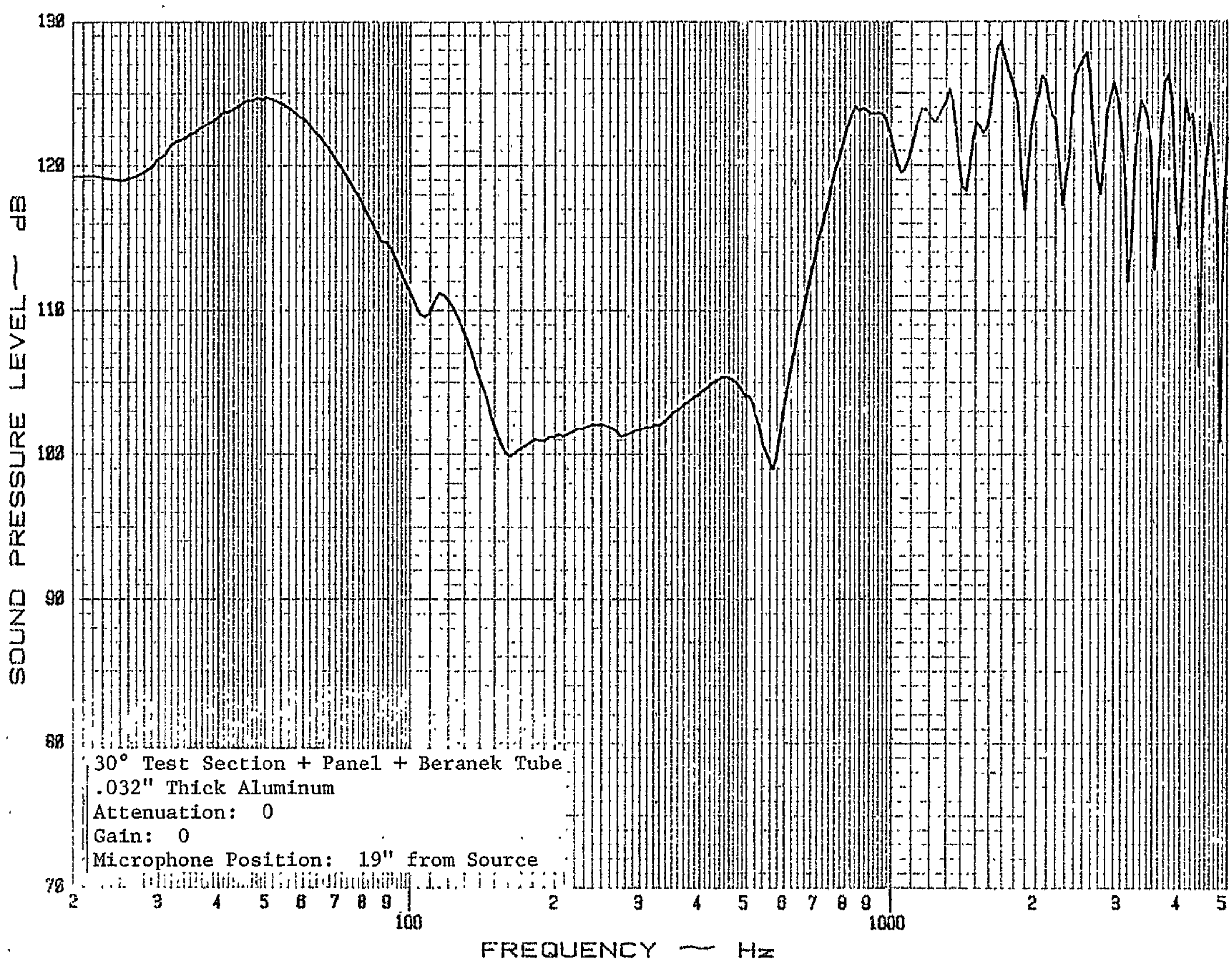

Figure 33: Experimental Sound Pressure Level for a Microphone Position at a Distance of 19" from the Speaker Baffle with a Test Panel Installed.

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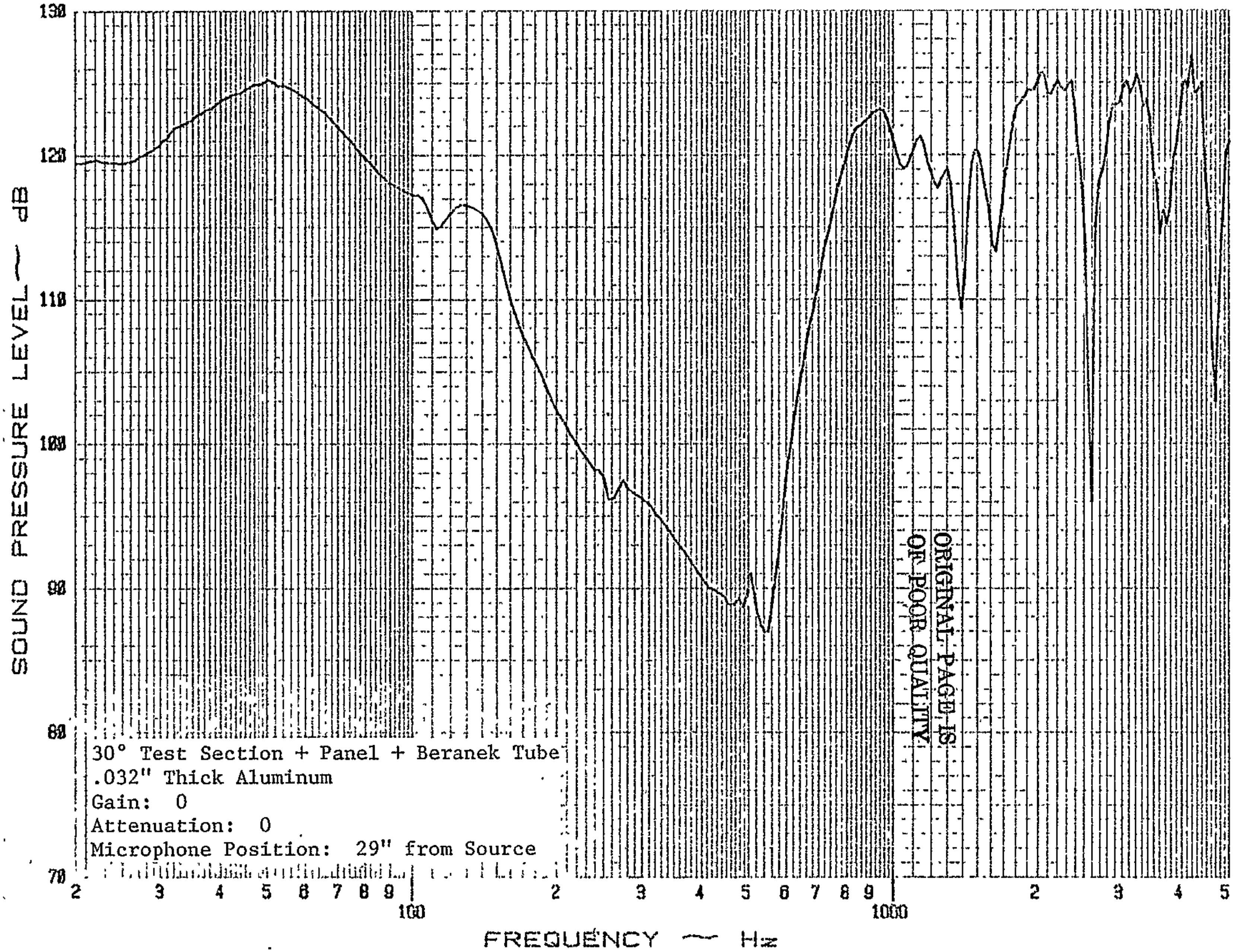

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Figure 34: Experimental Sound Pressure Level for a Microphone Position at a Distance of 29" from the Speaker Baffle with a Test Panel Installed.

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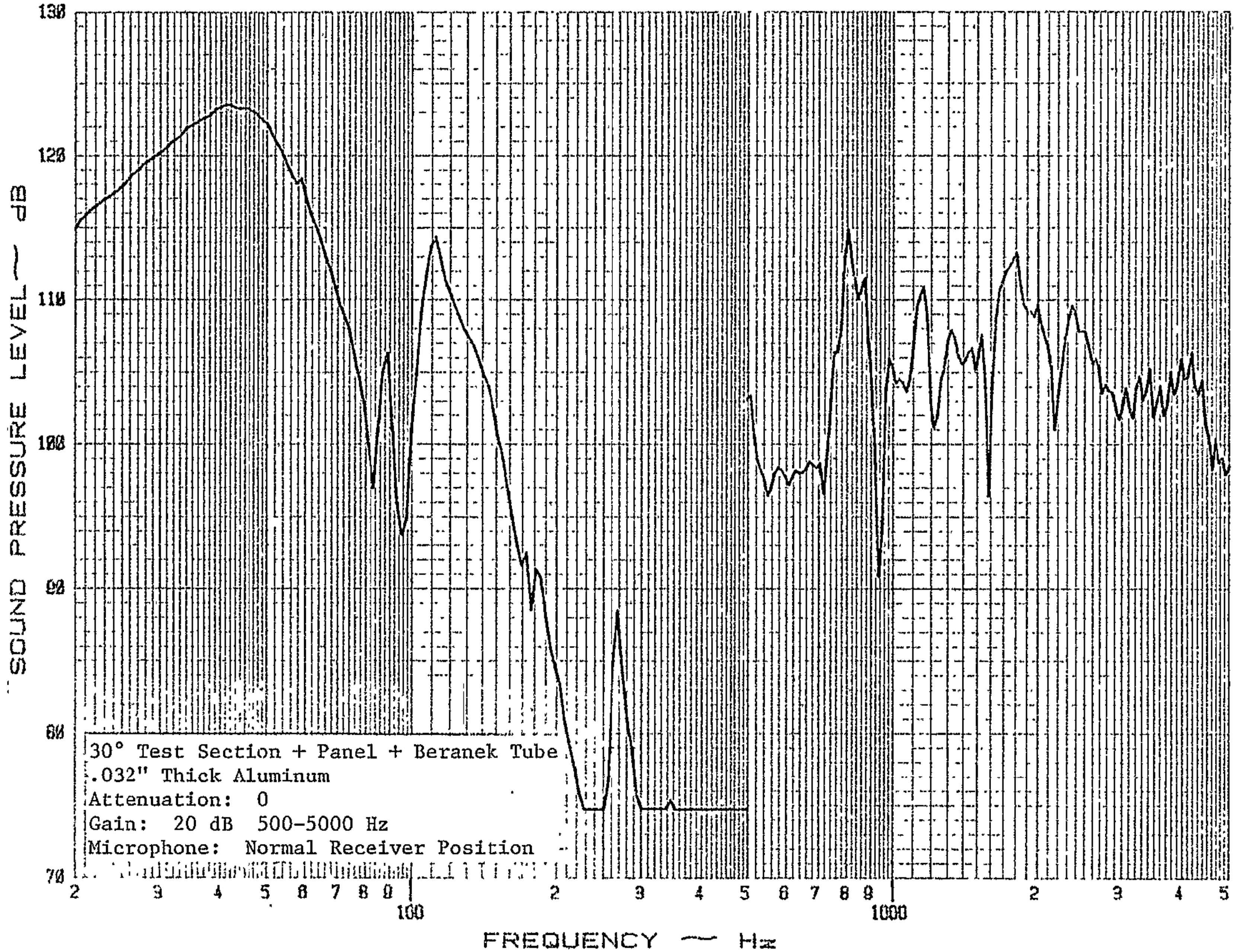

Figure 35: Experimental Sound Pressure Level for the Normal Receiver Microphone Position with a Test Panel Installed.

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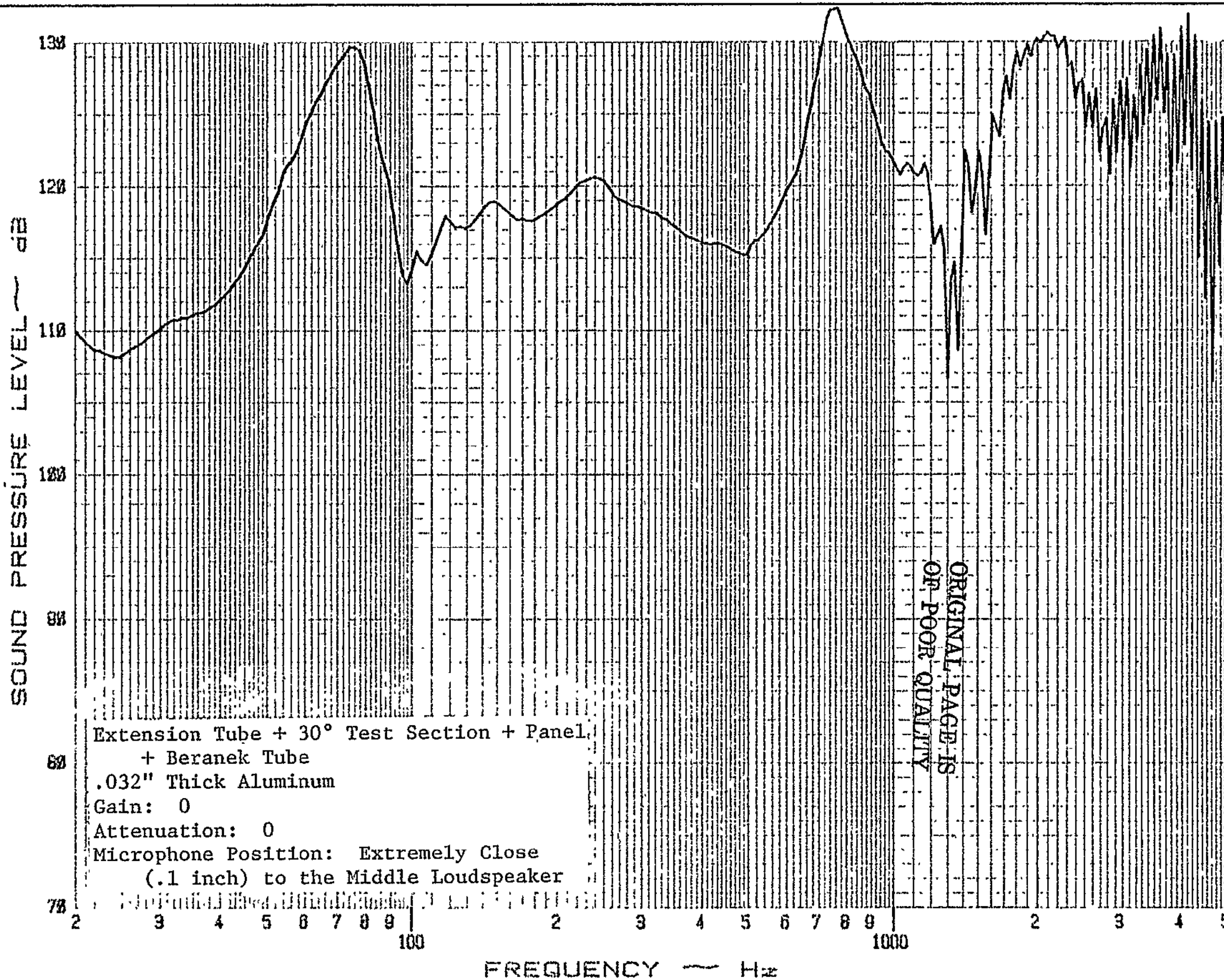

Figure 36: Experimental Sound Pressure Level for a Microphone Position Extremely Close to the Center Loudspeaker with a Test Panel Installed.

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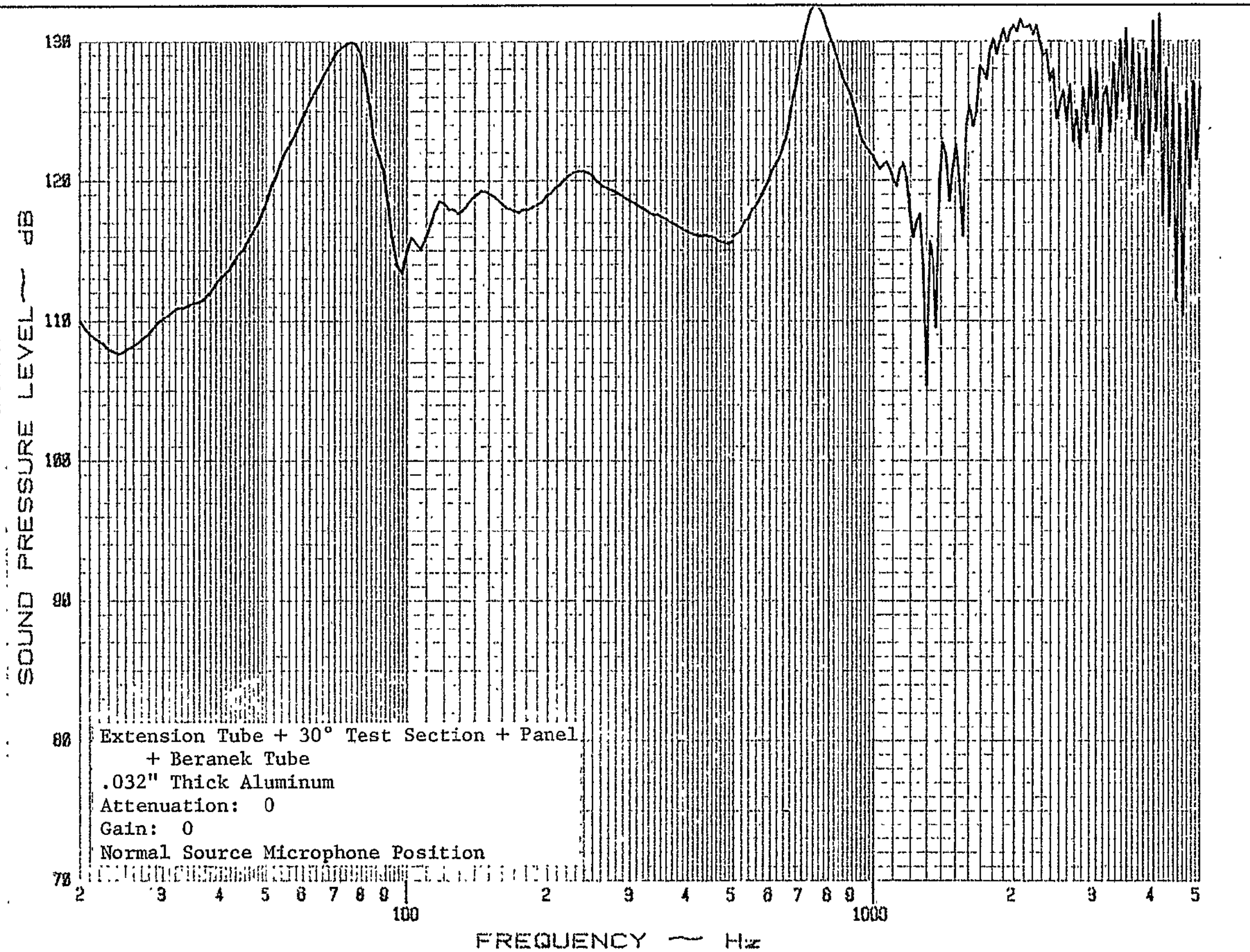

Figure 37: Experimental Sound Pressure Level for the Normal Source Microphone Position Using the Extension Tube and with a Test Panel Installed.

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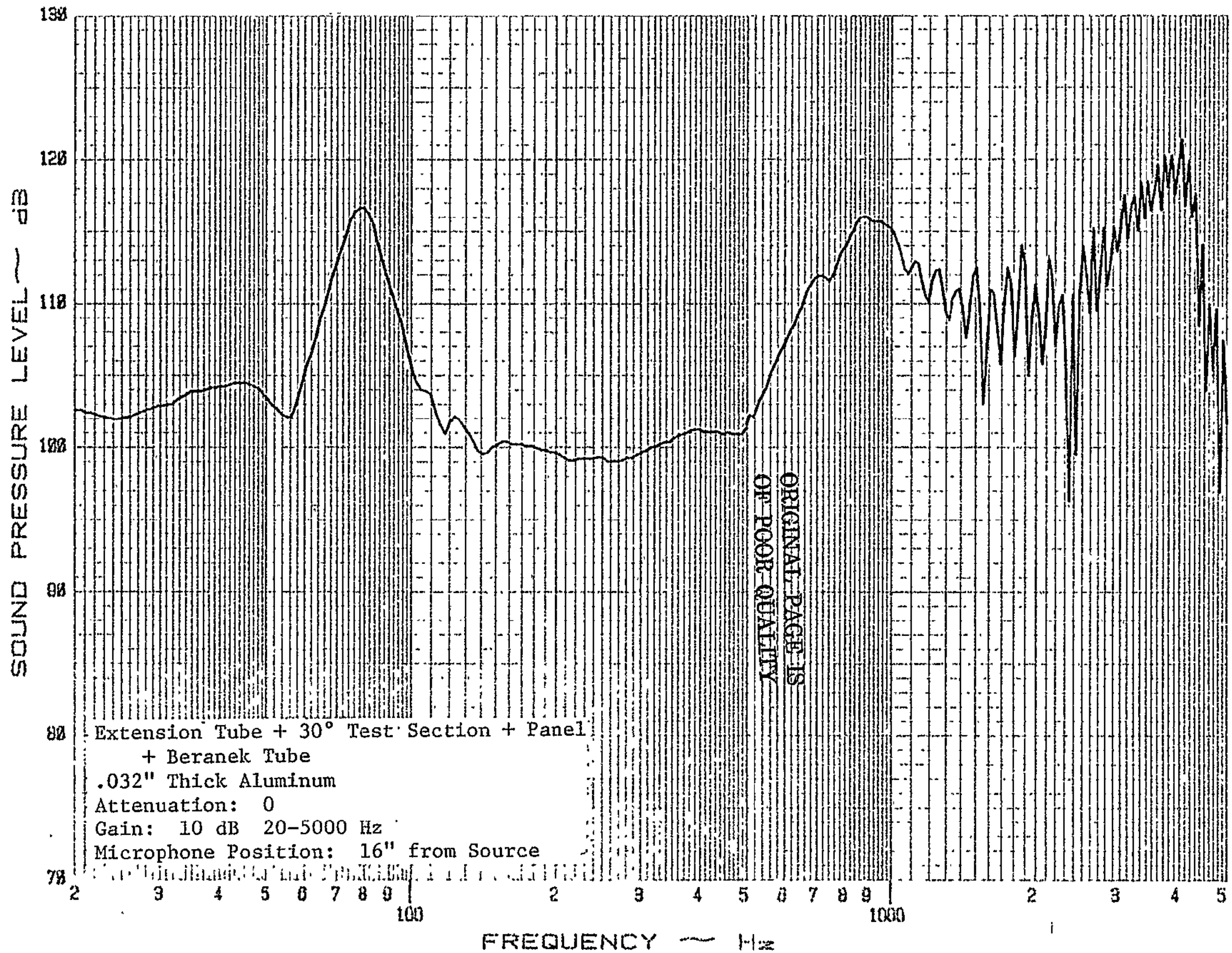

Figure 38: Experimental Sound Pressure Level for a Microphone Position at a Distance of 16" from the Speaker Baffle Using the Extension Tube and with a Test Panel Installed.

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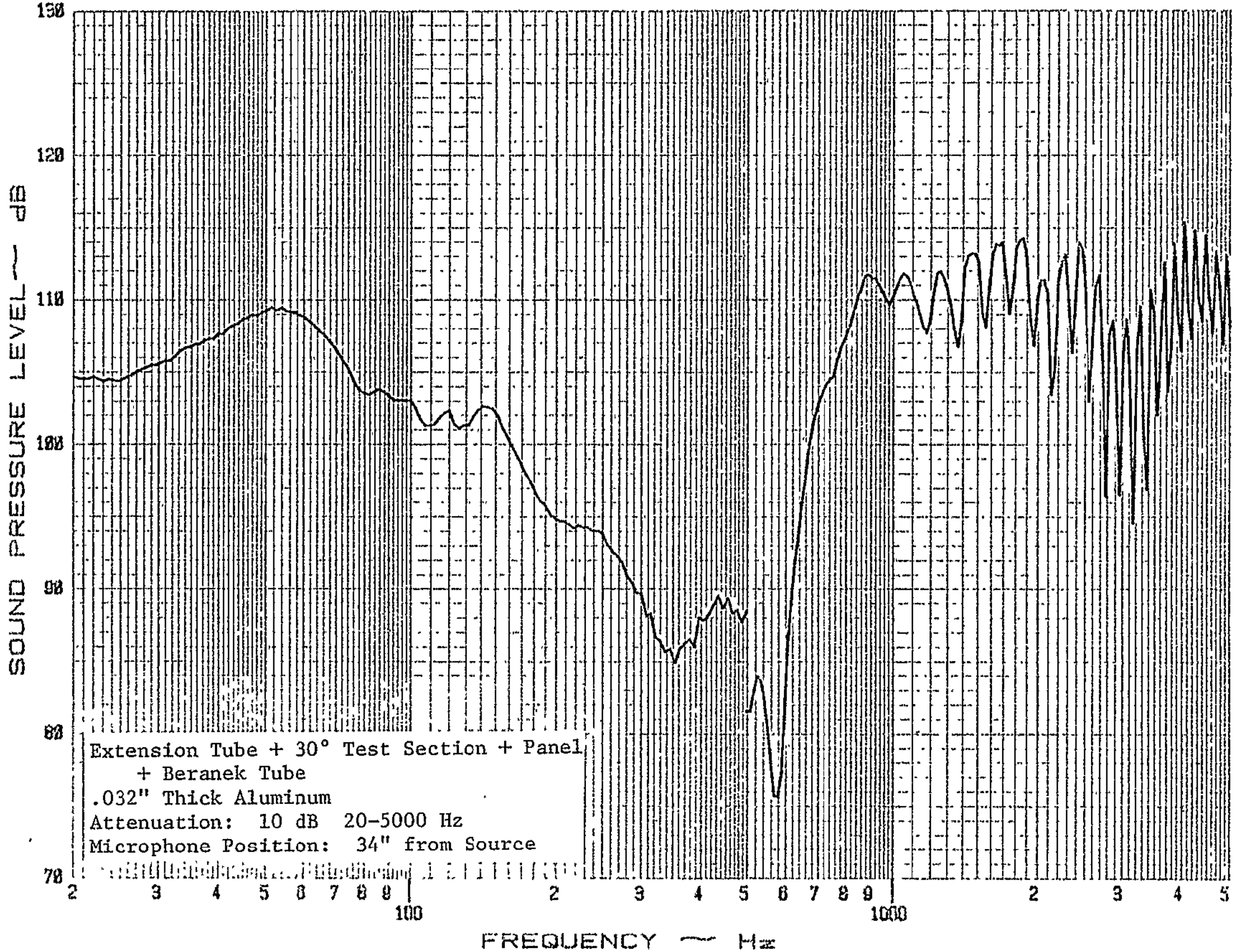

Figure 39: Experimental Sound Pressure Level for a Microphone Position at a Distance of 34" from the Speaker Baffle Using the Extension Tube and with a Test Panel Installed.

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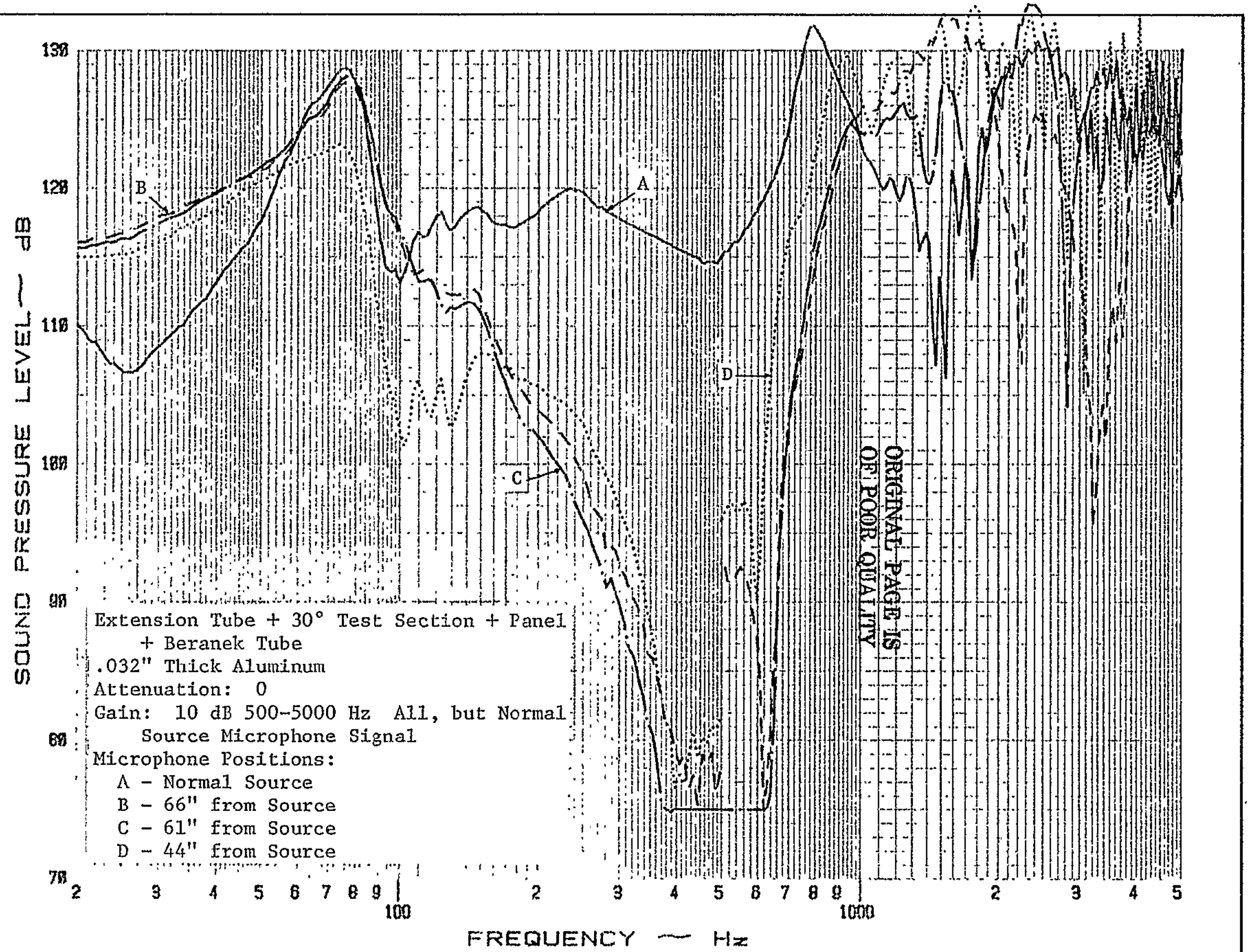

Figure 40: Experimental Sound Pressure Level for Various Microphone Positions Using the Extension Tube and with a Test Panel Installed.

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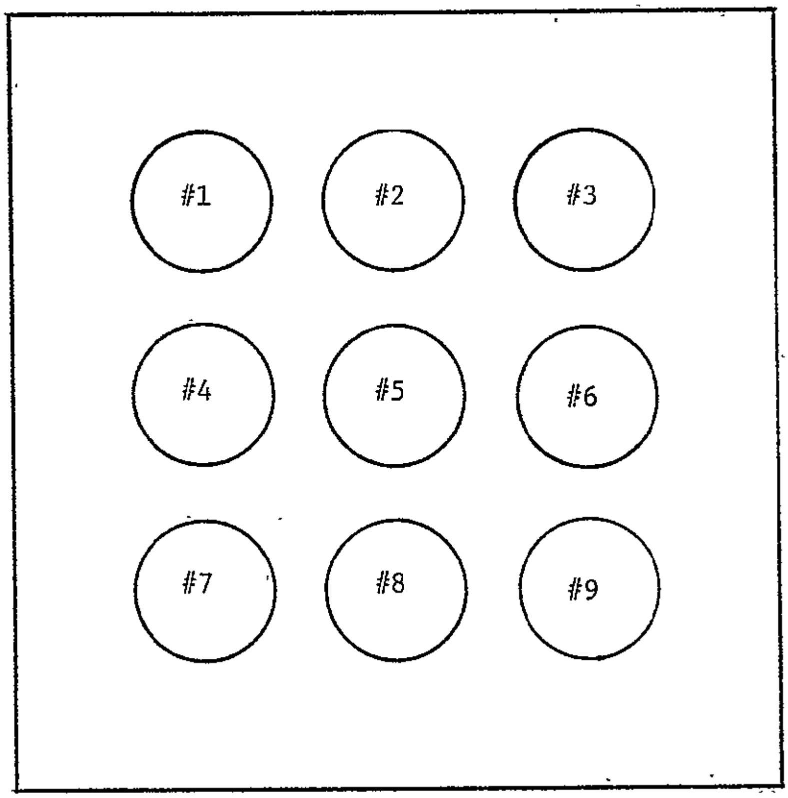

Figure 41: Locations of the Nine Evenly Spaced Loudspeakers.

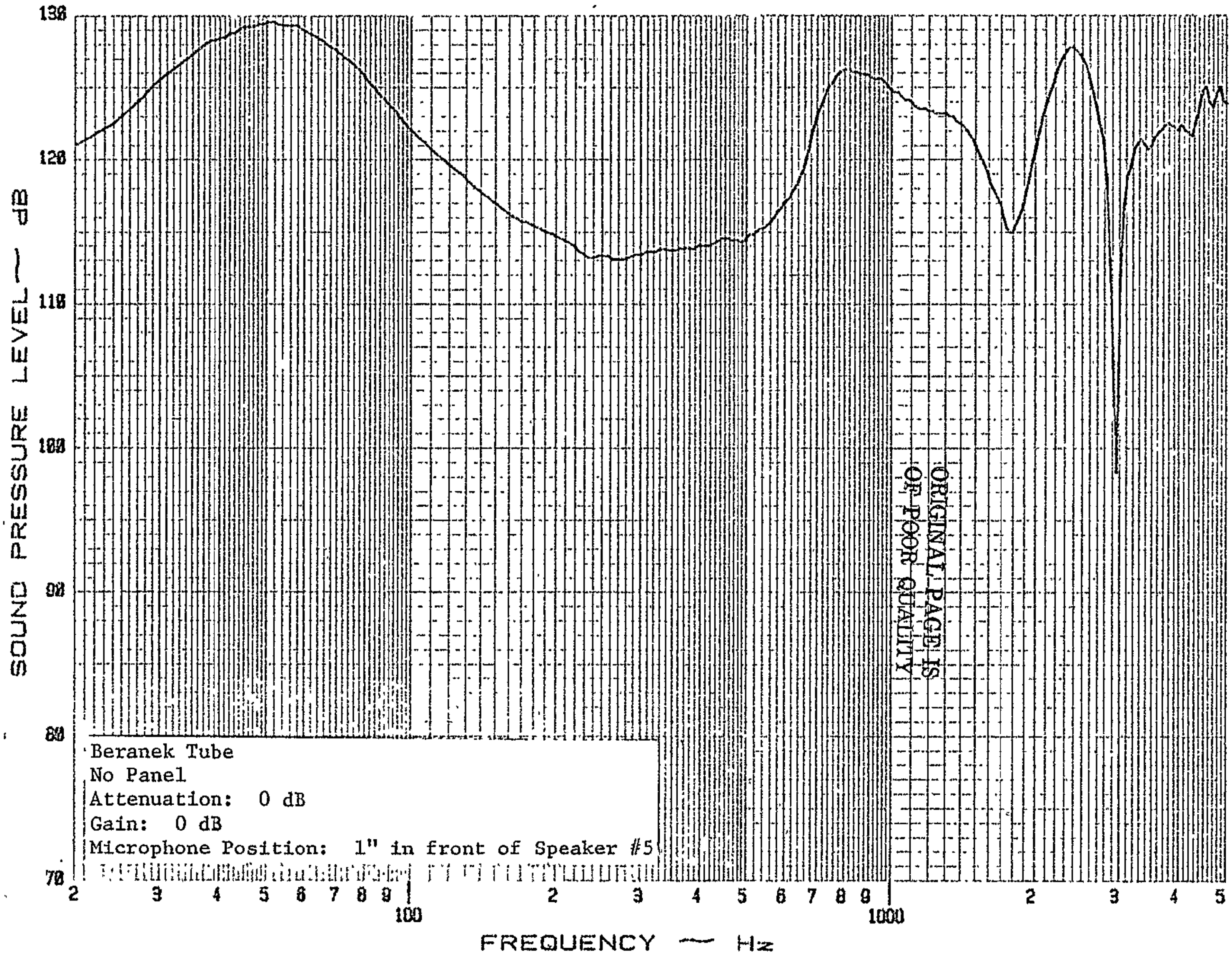

Figure 42: Experimental Sound Pressure Level for a Microphone Position in the Center of a Cross Section at a Distance of 1" from the Speaker Baffle.

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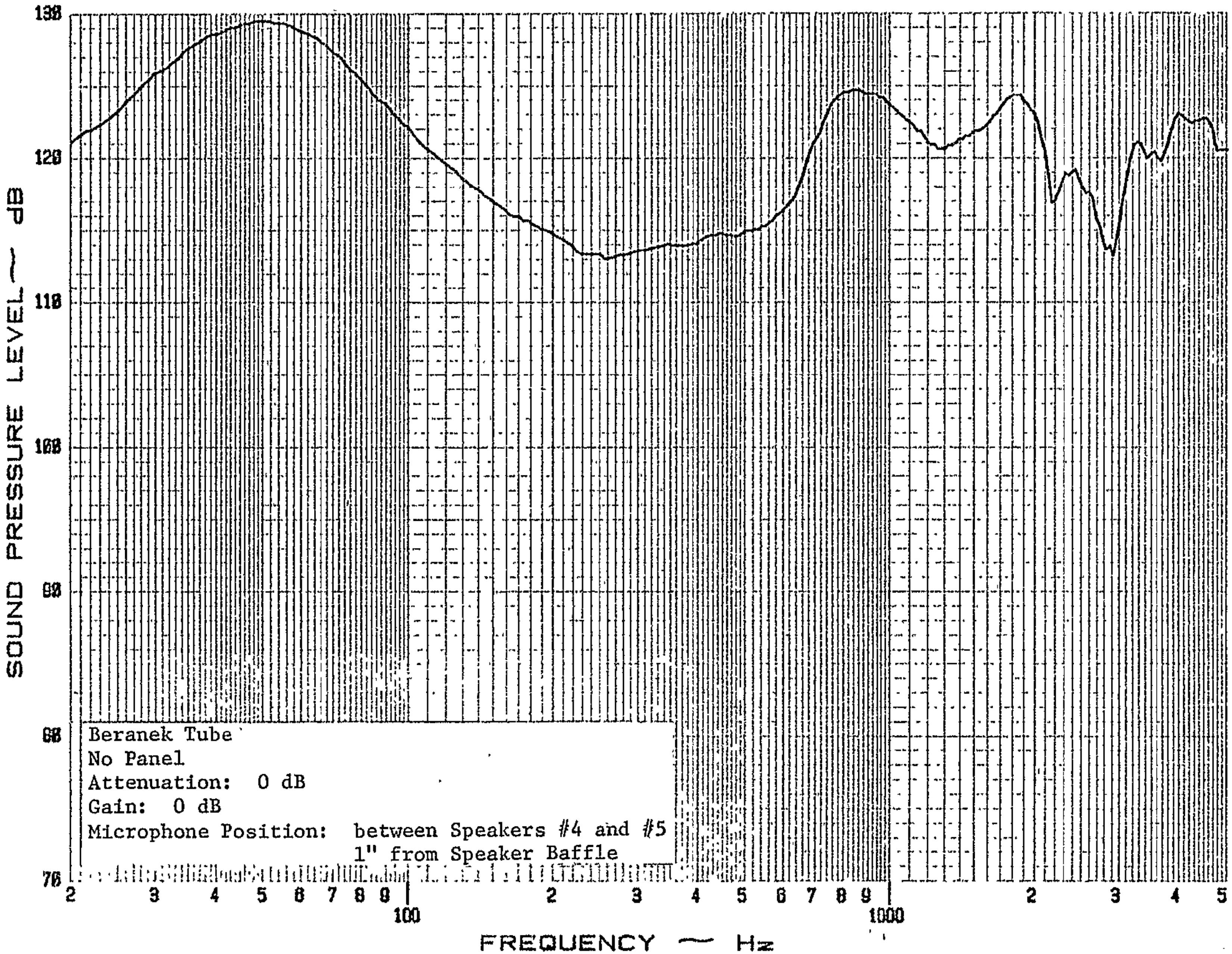

Figure 43: Experimental Sound Pressure Level for an Off-Center Microphone Position in a Cross Section at a Distance of 1" from the Speaker Baffle.

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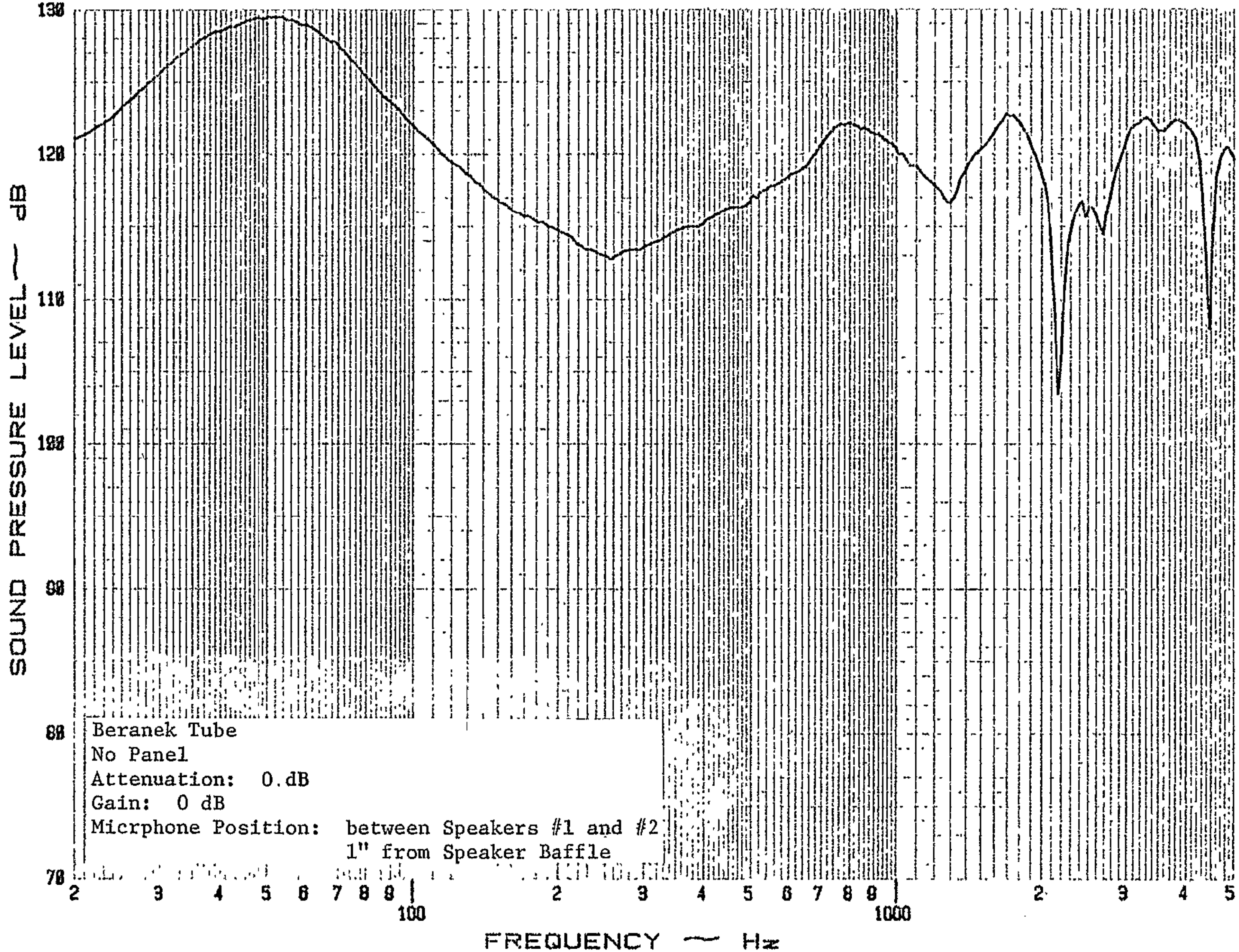

Figure 44: Experimental Sound Pressure Level for an Off-Center Microphone Position in a Cross Section at a Distance of 1" from the Speaker Baffle.

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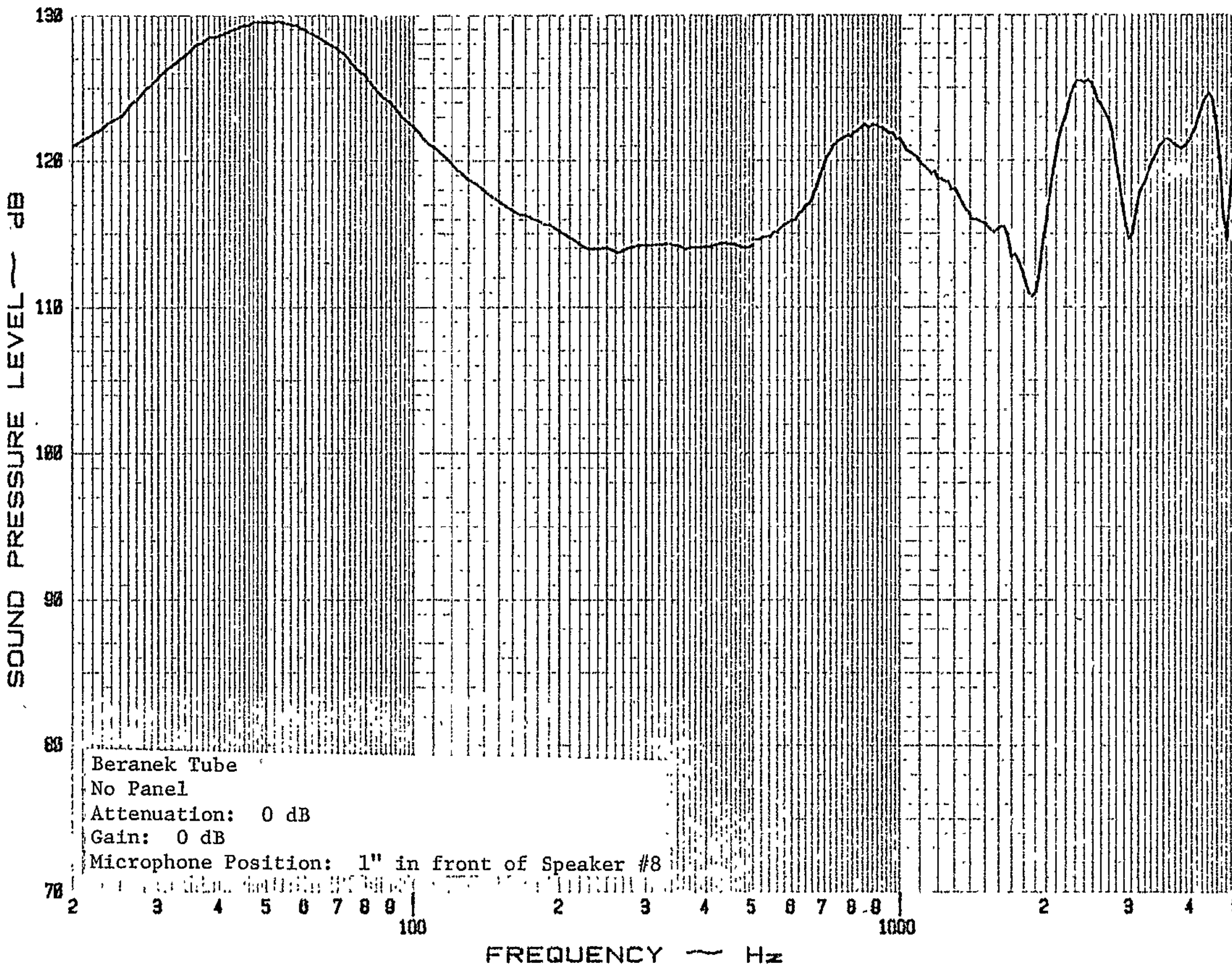

Figure 45: Experimental Sound Pressure Level for a Microphone Position at a Distance of 1" in Front of Speaker #8.

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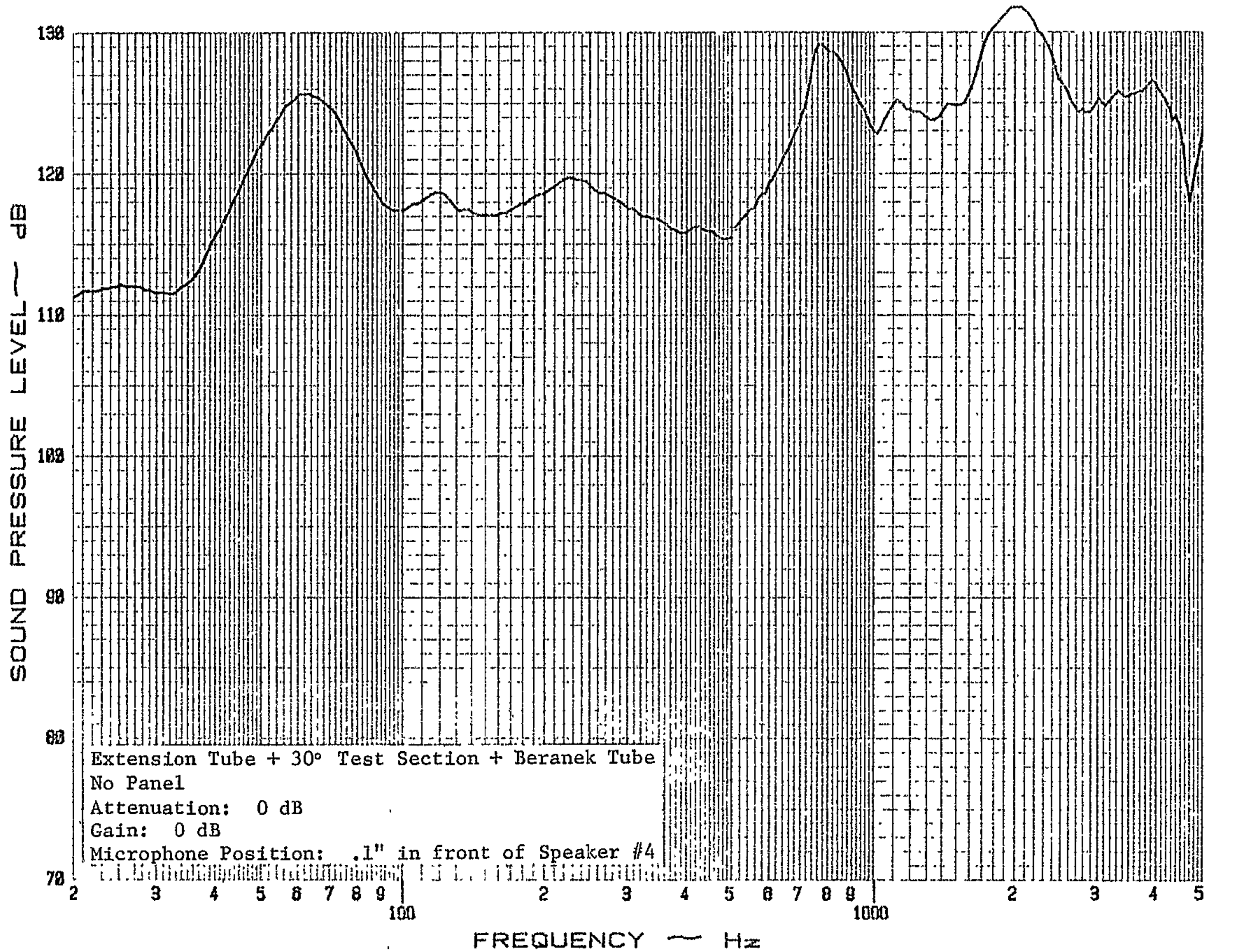

Figure 46: Experimental Sound Pressure Level for a Microphone Position Extremely Close to Speaker #4.

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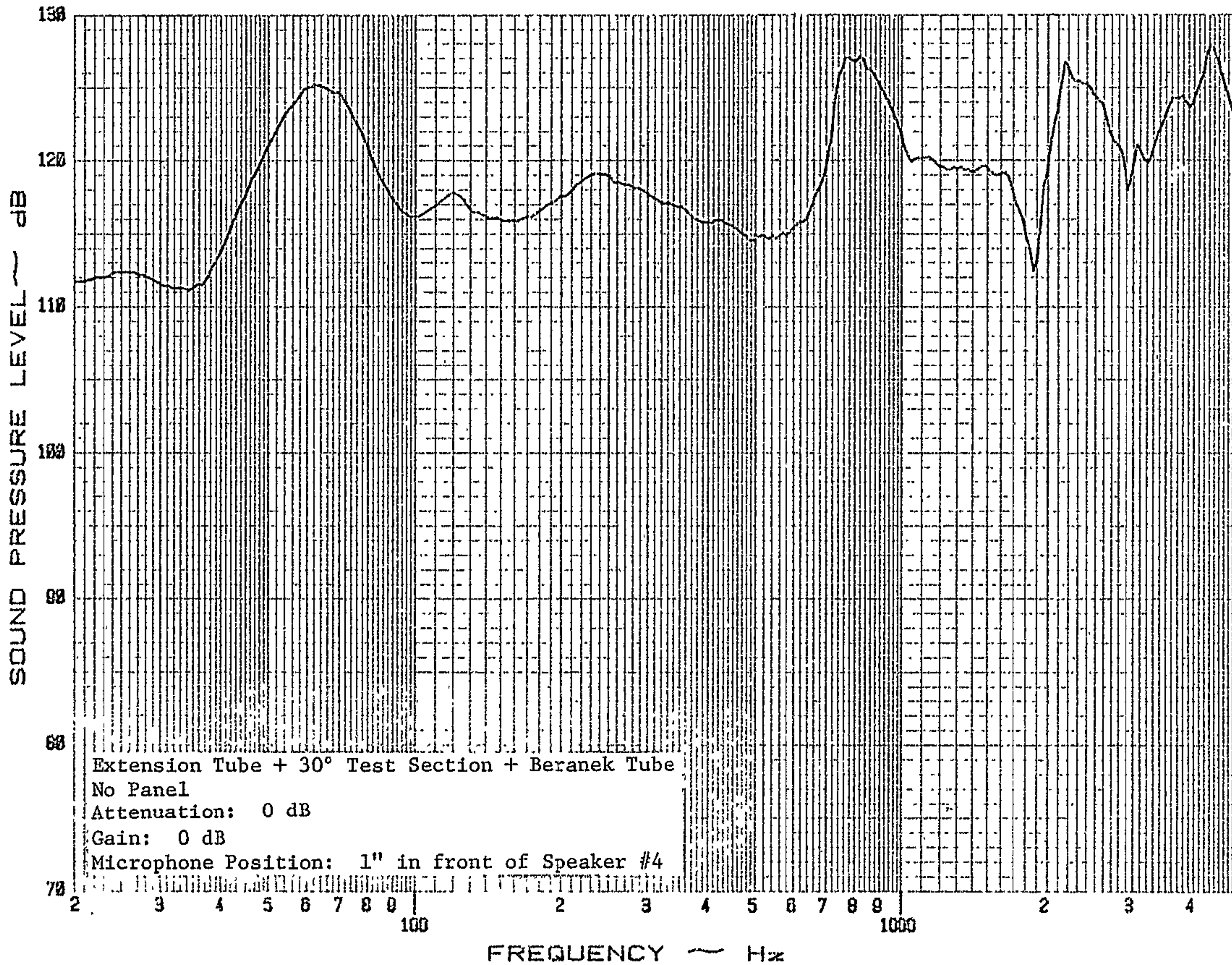

Figure 47: Experimental Sound Pressure Level for a Microphone Position at a Distance of 1" in Front of Speaker #4.

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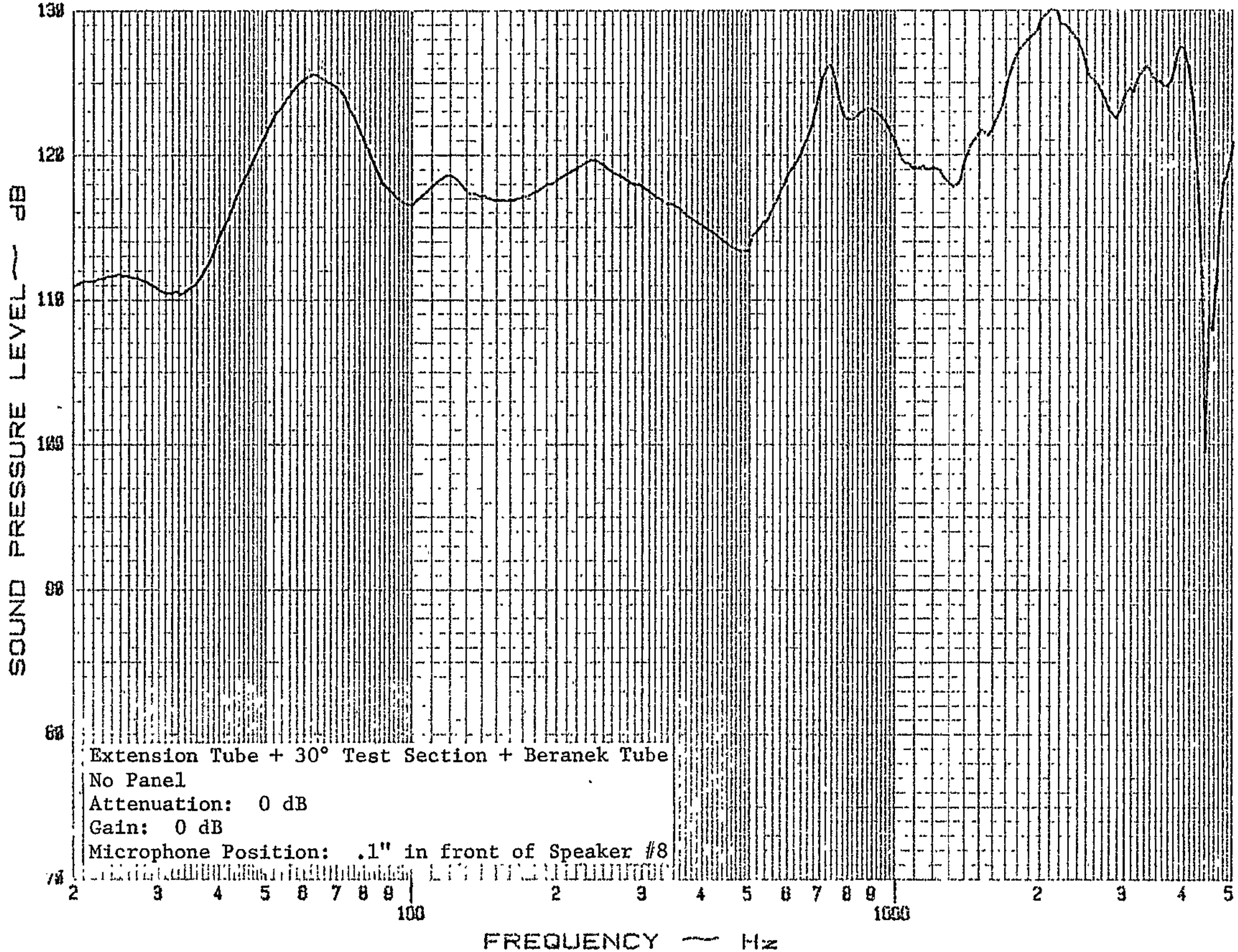

Figure 48: Experimental Sound Pressure Level for a Microphone Position Extremely Close to Speaker #8.

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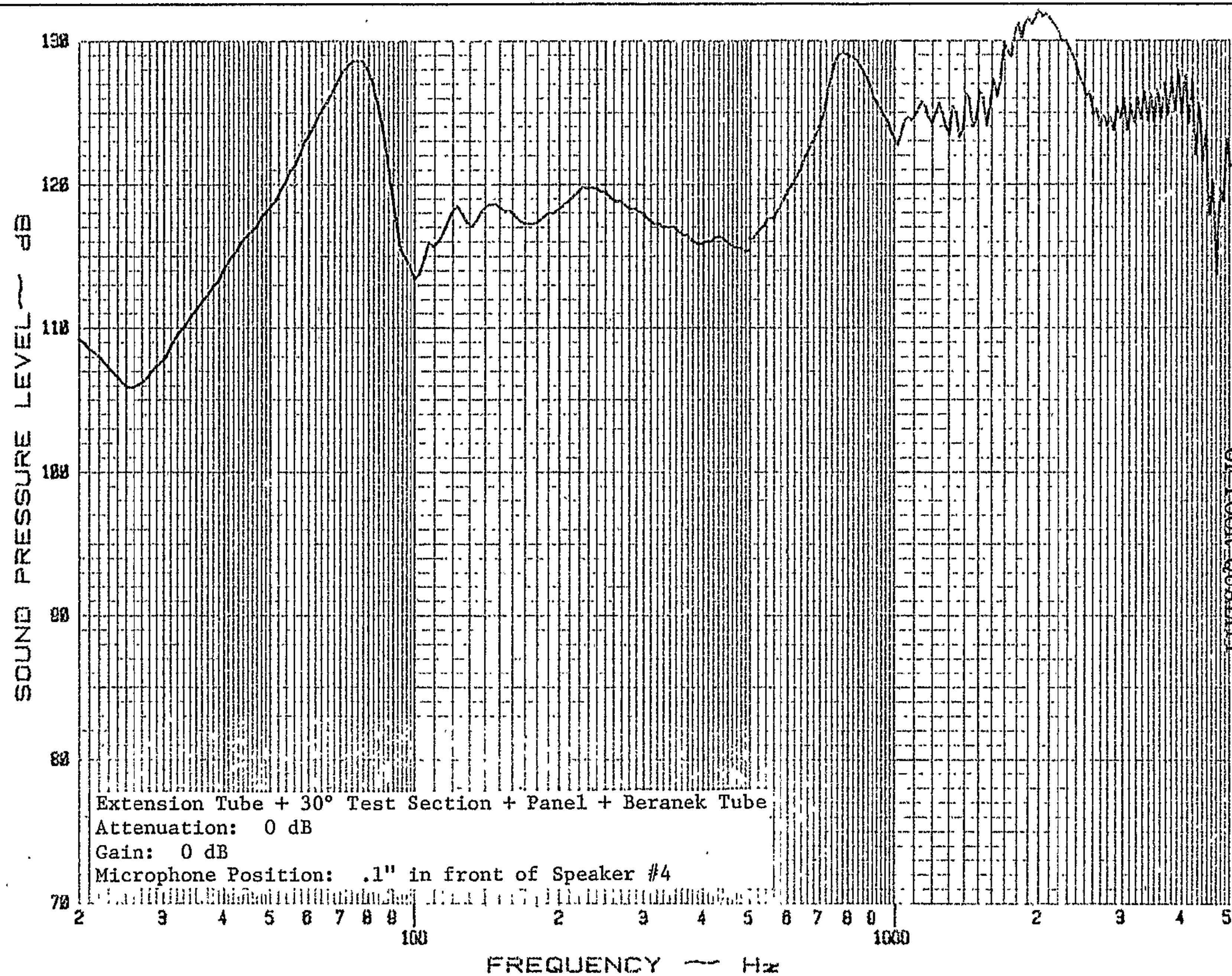

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Figure 49: Experimental Sound Pressure Level for a Microphone Position Extremely Close to Speaker #4, with a Test Panel Installed.

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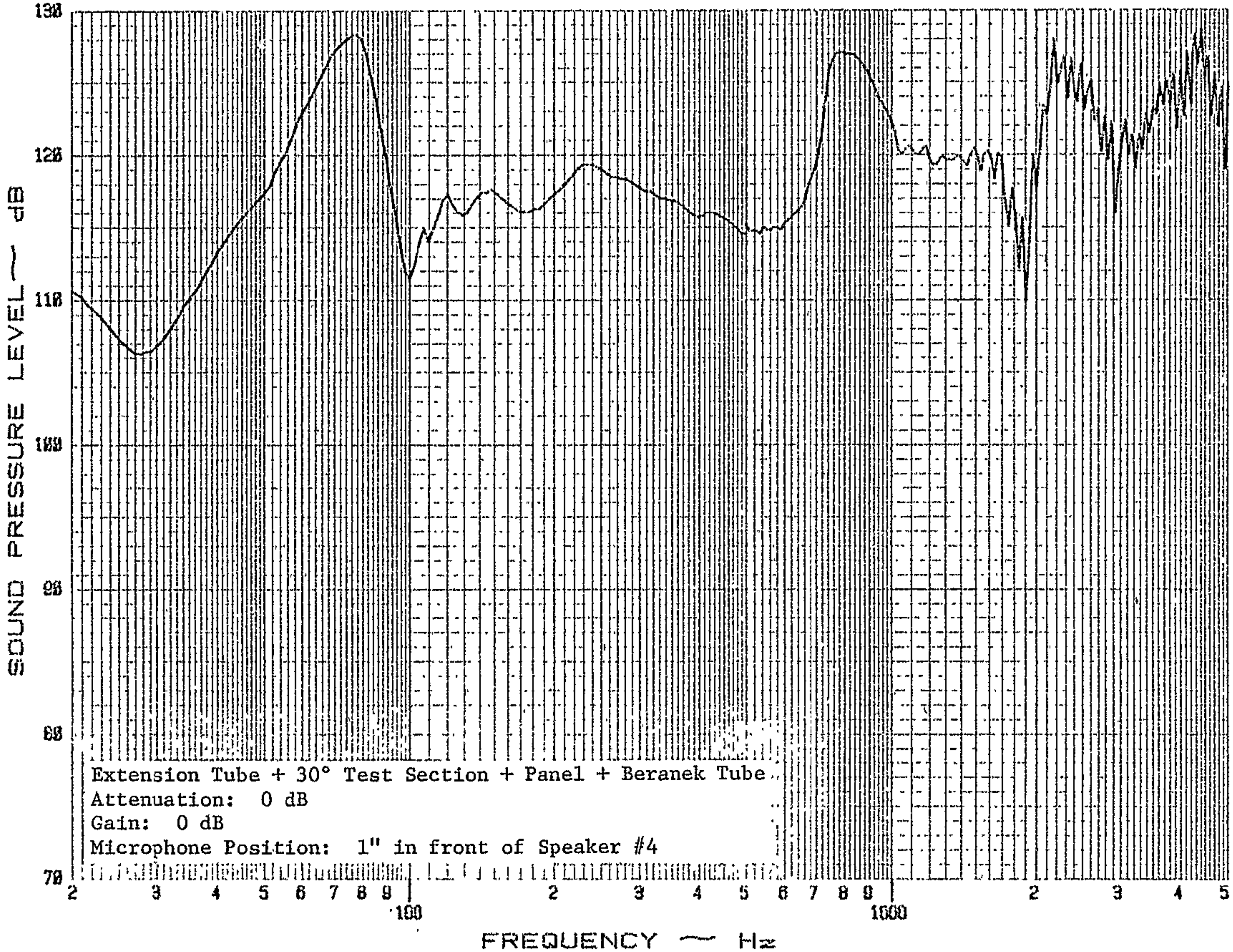

Figure 50: Experimental Sound Pressure Level for a Microphone Position at a Distance of 1" in Front of Speaker #4,with a Test Panel Installed.

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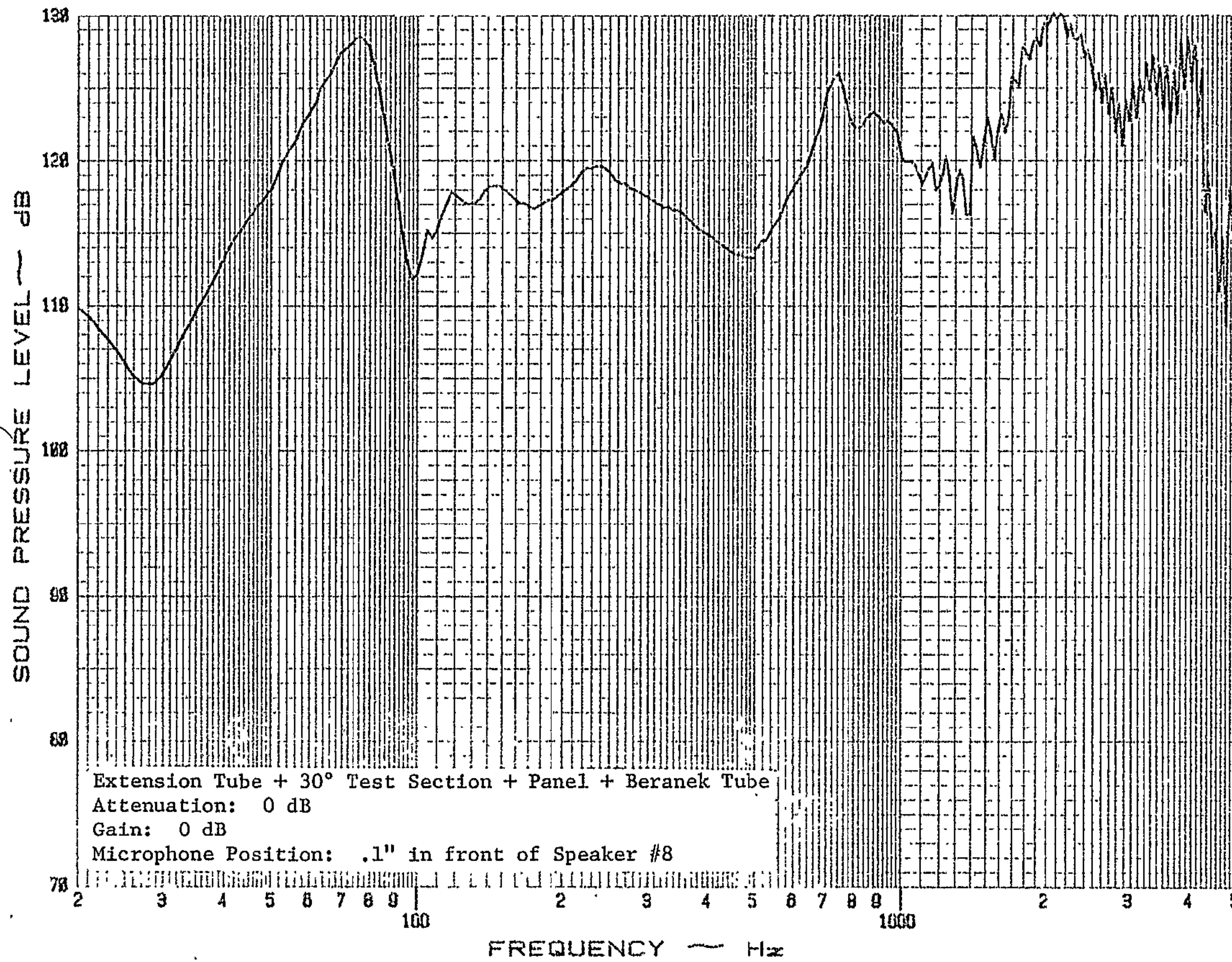

Figure 51: Experimental Sound Pressure Level for a Microphone Position Extremely Close to Speaker #8, with a Test Panel Installed.

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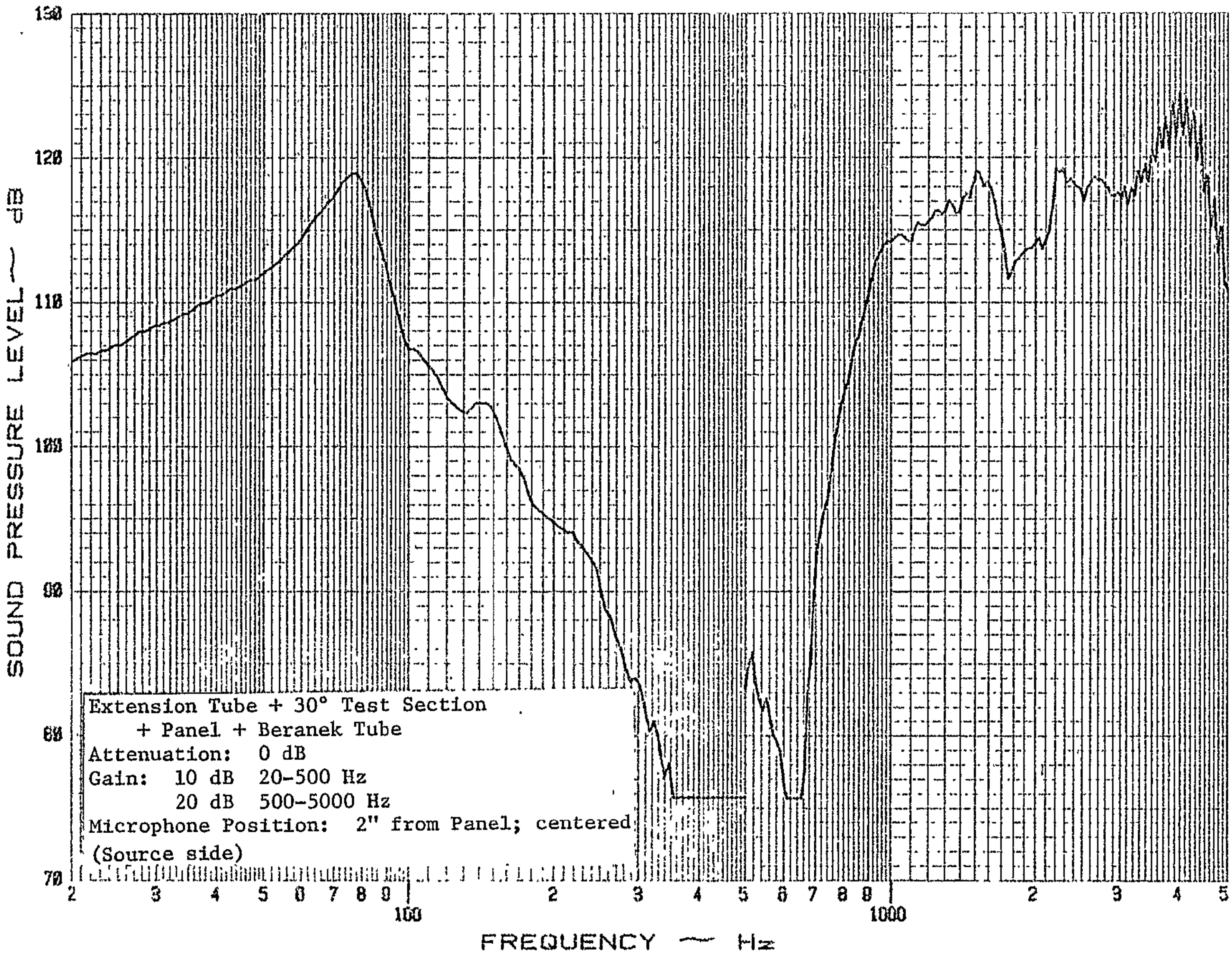

Figure 52: Experimental Sound Pressure Level for a Microphone Position in the Center of a Cross Section 2" from the Test Panel at the Source Side.

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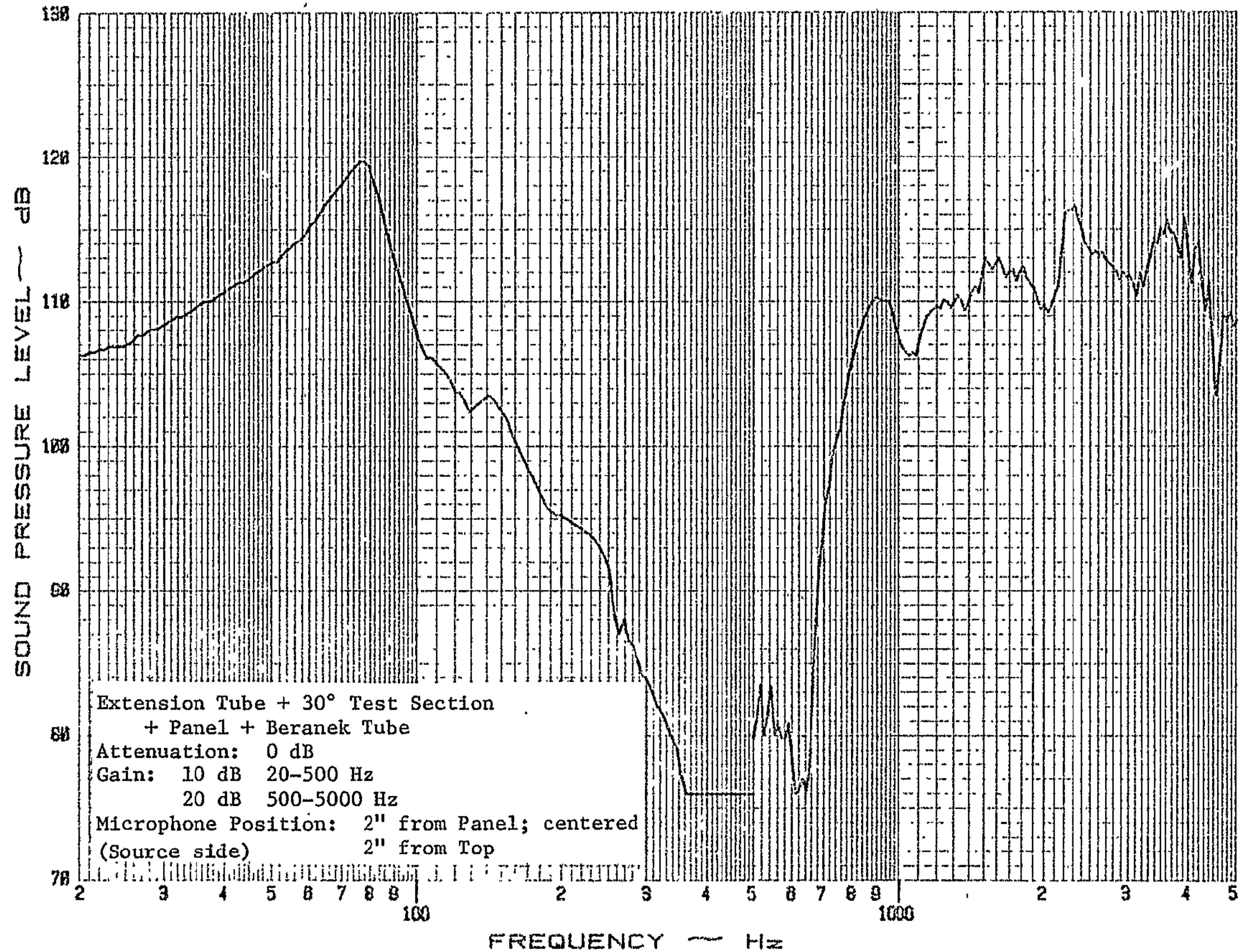

Figure 53: Experimental Sound Pressure Level for a Microphone Position on the Vertical Axis, 2" from the Top, in a Cross Section 2" from the Test Panel at the Source Side.

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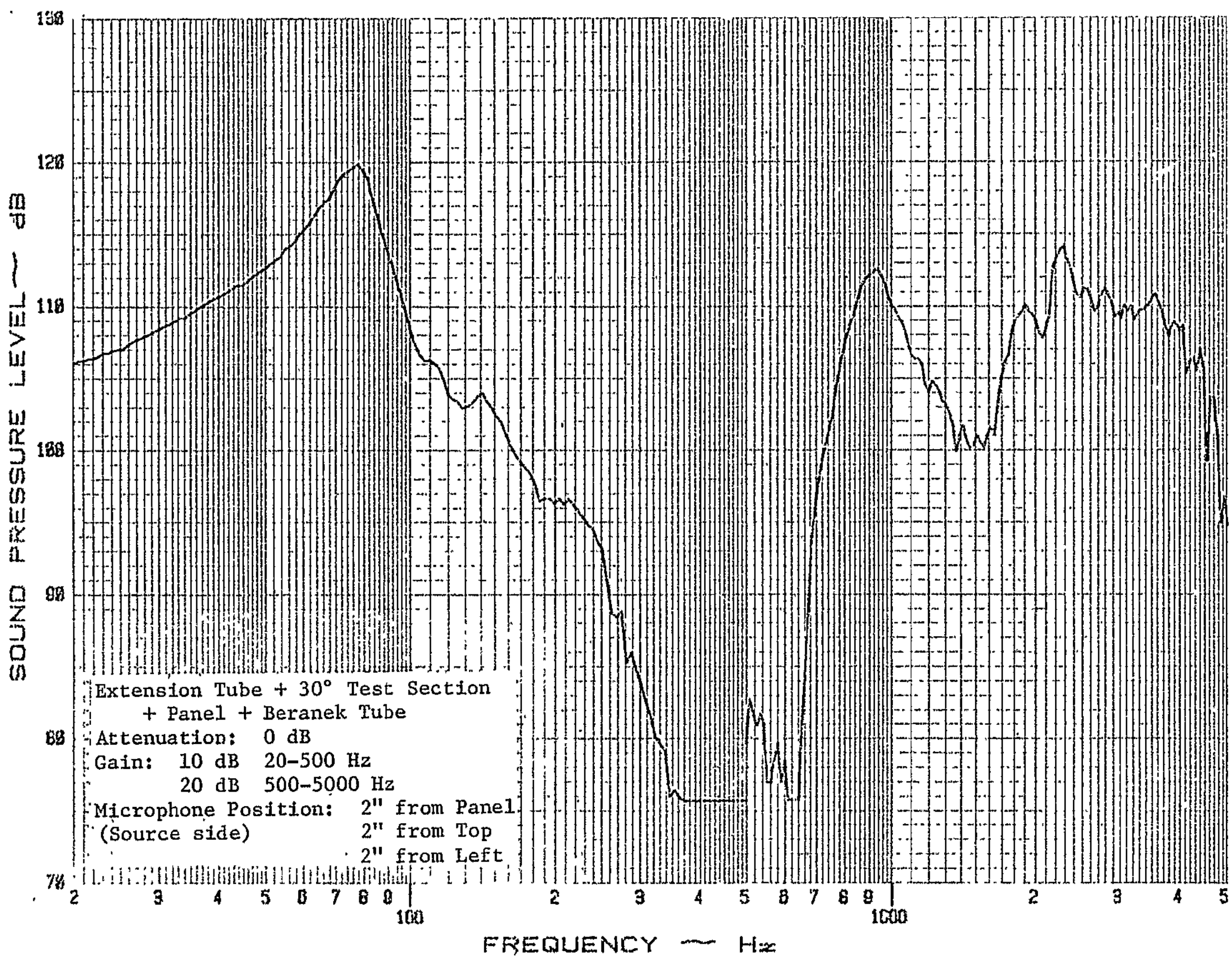

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Figure 54: Experimental Sound Pressure Level for a Microphone Position in a Cross Section 2" from the Test Panel at the Source Side and 2" from the Top and 2" from the Left Side.

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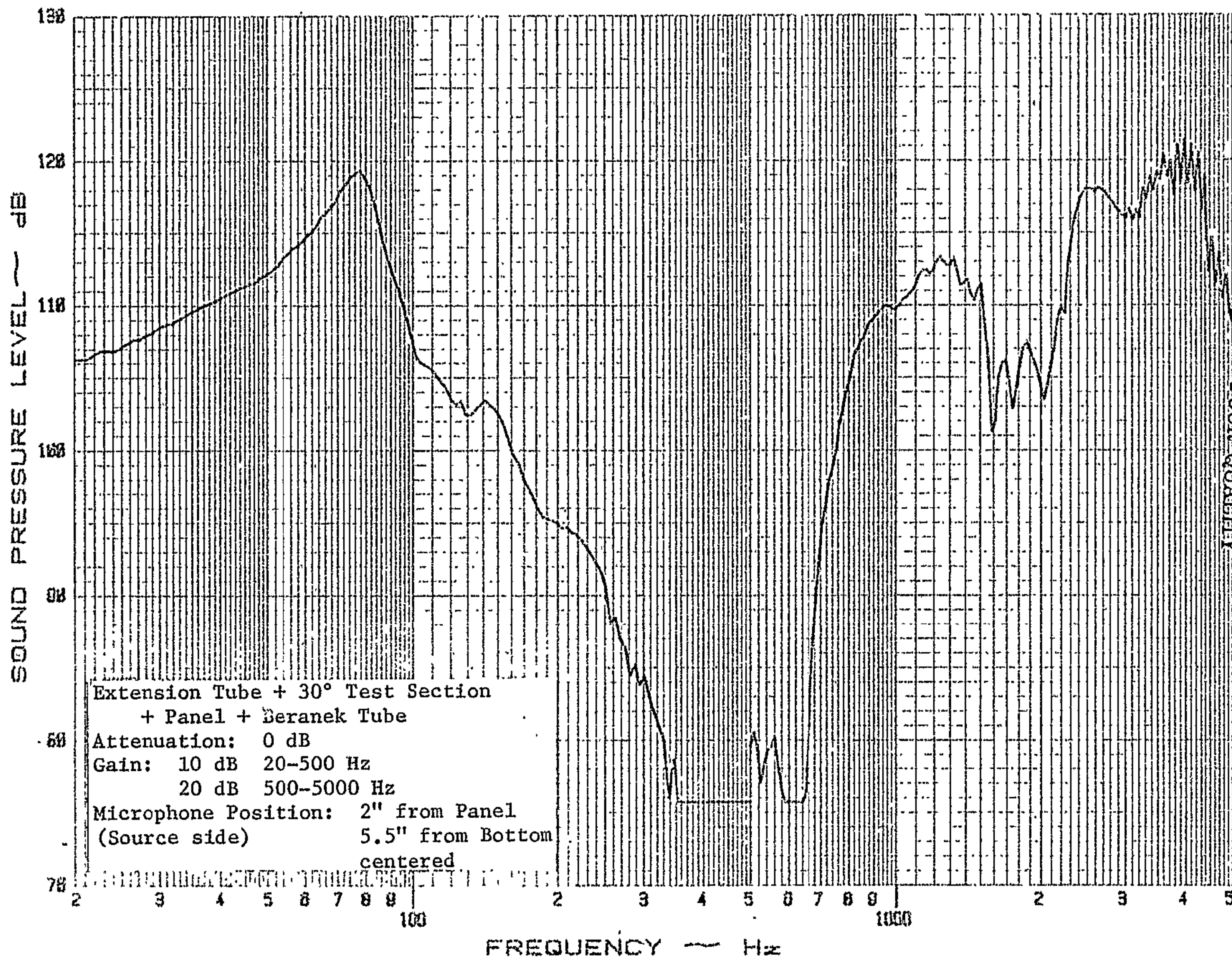

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Figure 55: Esperimental Sound Pressure Level for a Micro-phone Position on the Vertical Axis, 5.5" from the Bottom, in a Cross Section 2" from the Test Panel at the Source Side.

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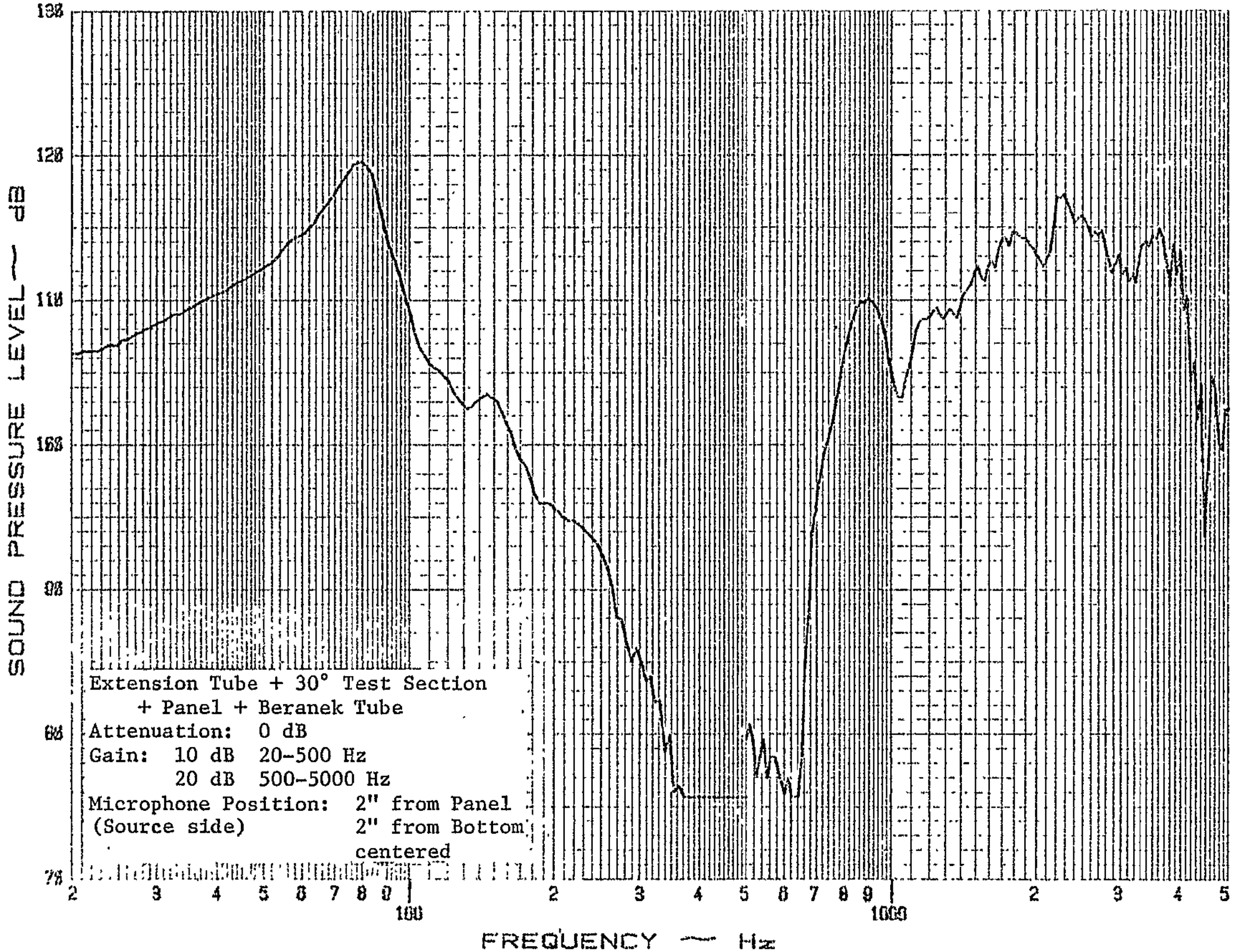

Figure 56: Experimental Sound Pressure Level for a Microphone Position on the Vertical Axis, 2" from the Bottom, in a Cross Section 2" from the Test Panel at the Source Side.

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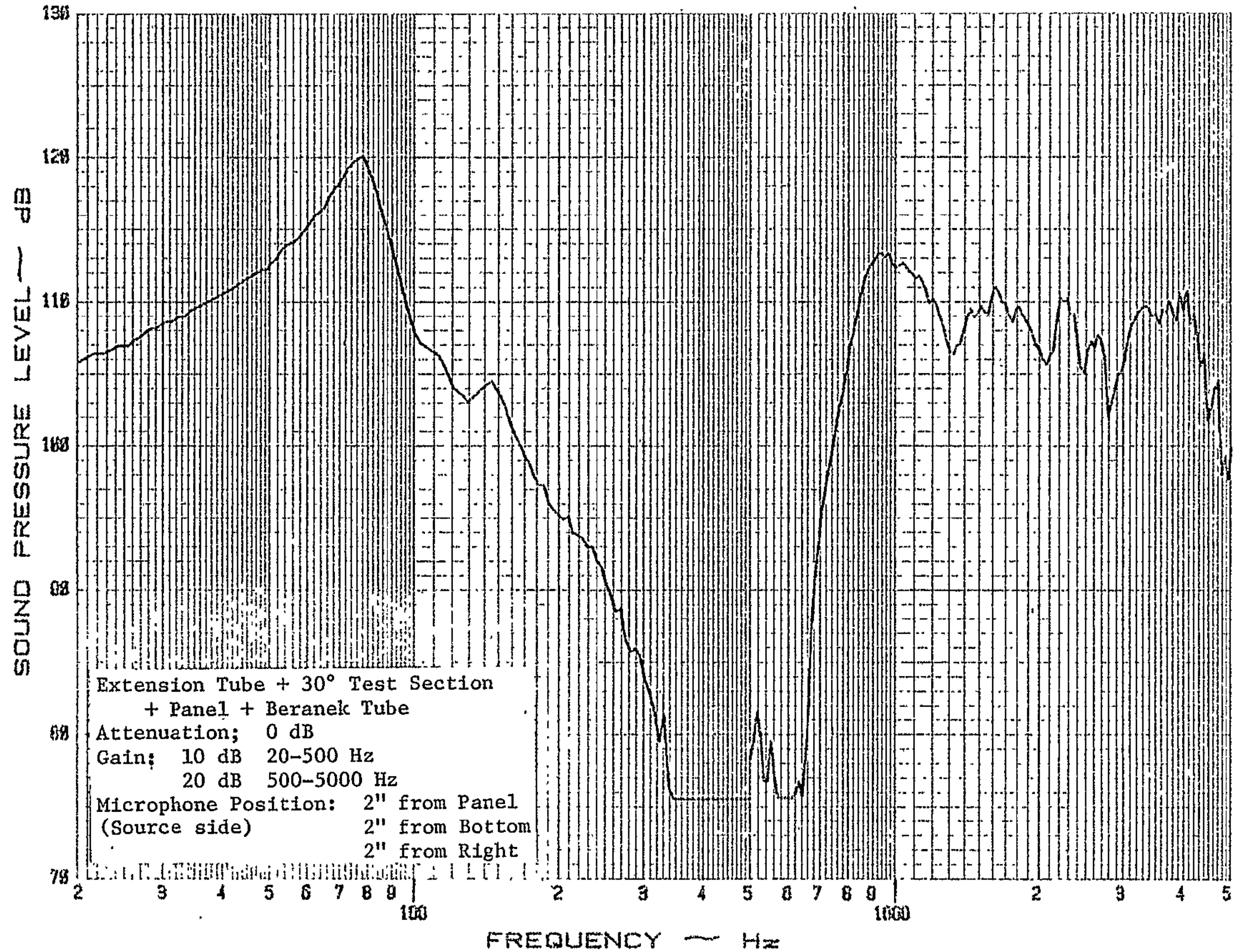

Figure 57: Experimental Sound Pressure Level for a Microphone Position in a Cross Section at 2" from the Test Panel at the Source Side, 2" from the Bottom and 2" from the Right Side.

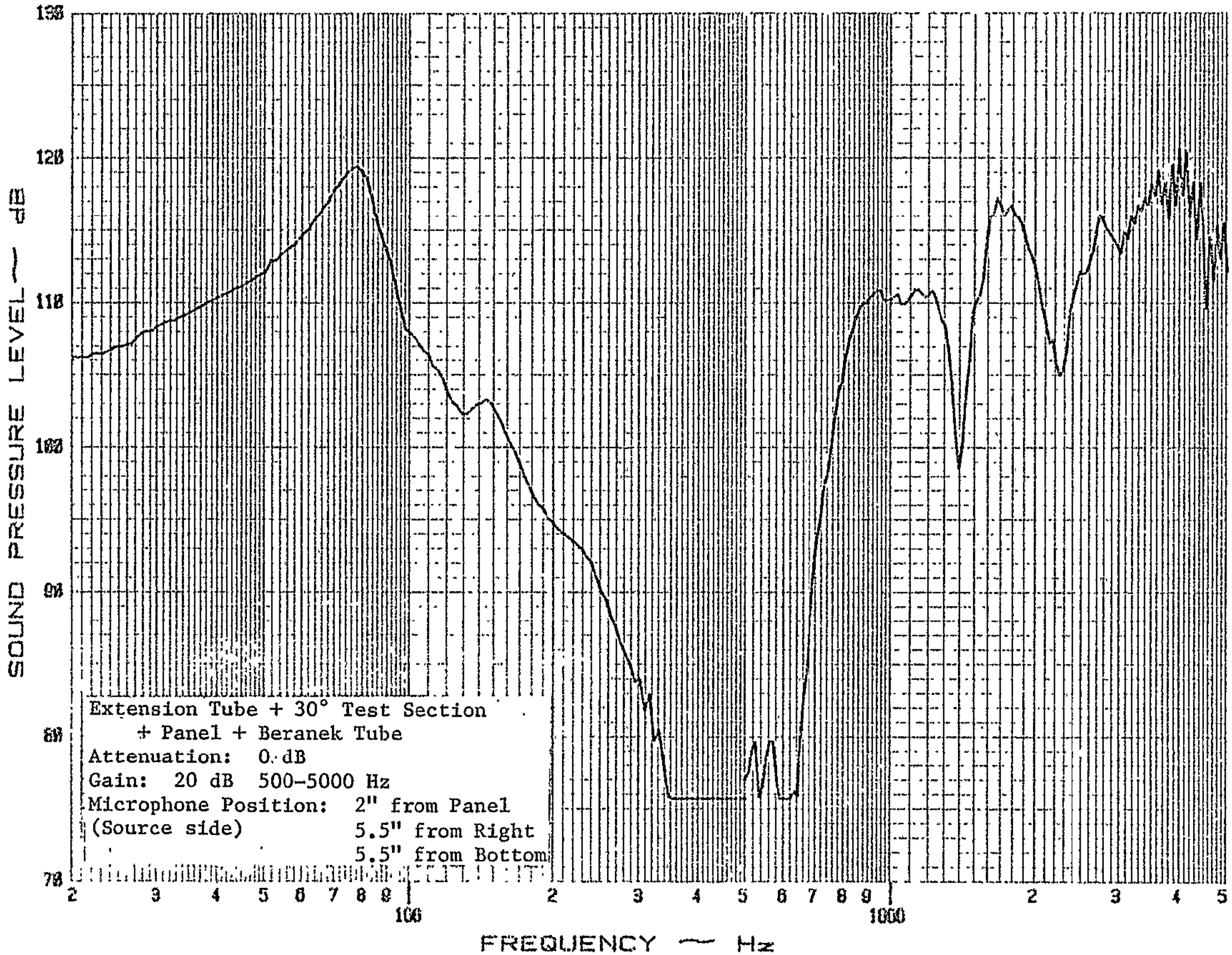

Figure 58: Experimental Sound Pressure Level for a Microphone Position in a Cross Section at 2" from the Test Panel at the Source Side, 5.5" from the Bottom and 5.5" from the Right Side.

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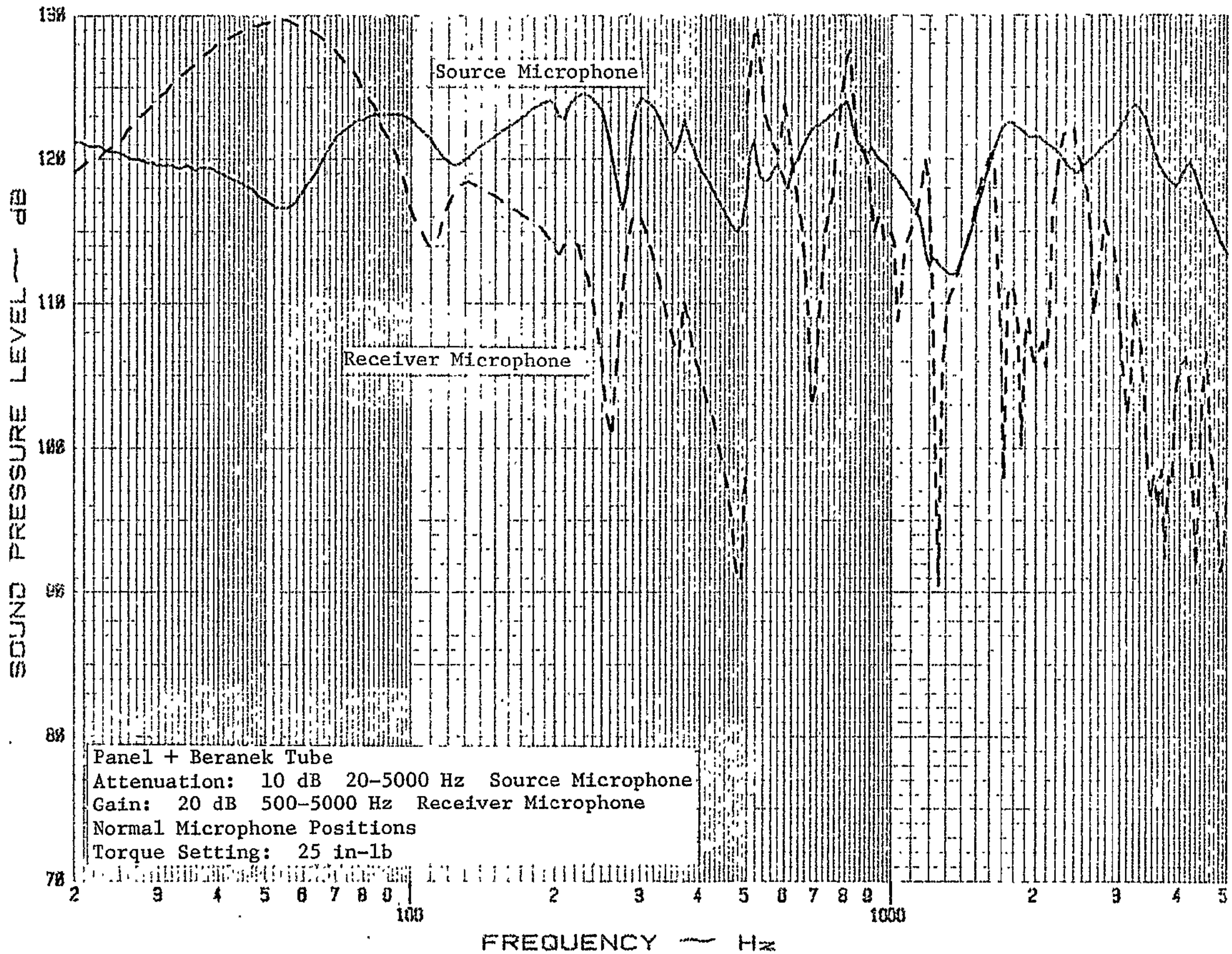

Figure 59: Experimental Sound Pressure Levels for a Torque Setting of 25 in-lb, with a .032 inch Thick Aluminum Panel Installed.

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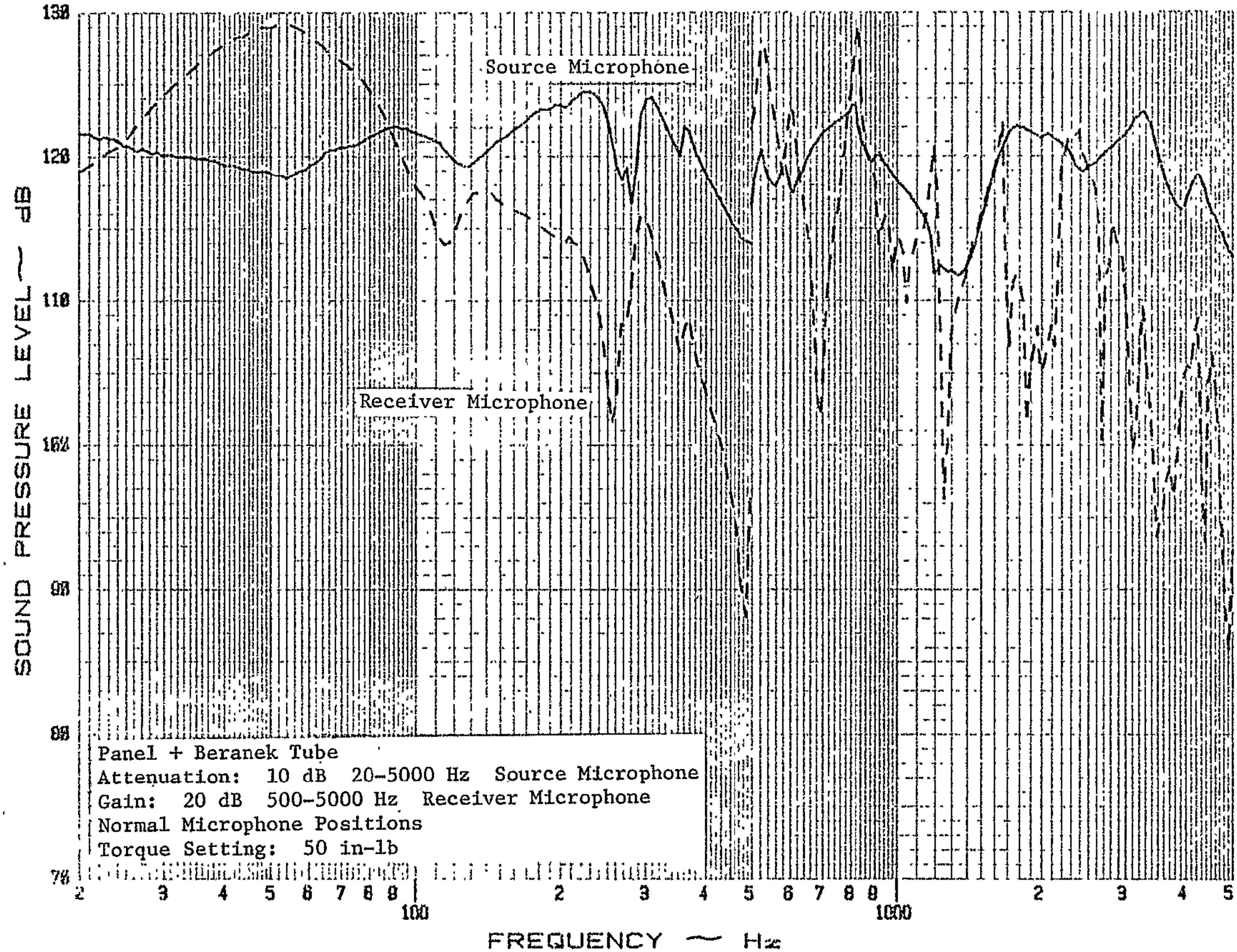

Figure 60: Experimental Sound Pressure Levels for a Torque Setting of 50 in-lb, with a .032 inch Thick Aluminum Test Panel Installed.

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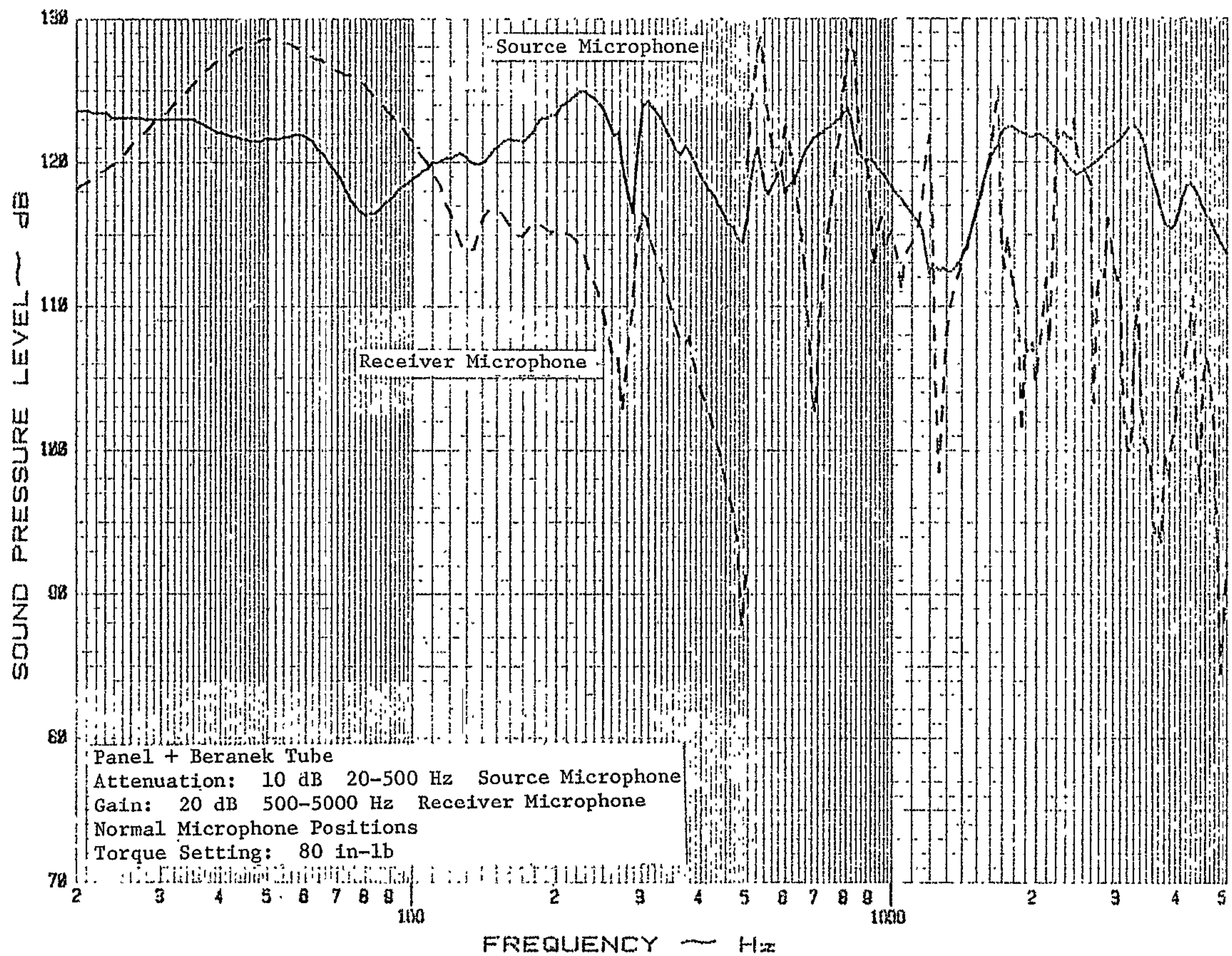

Figure 61: Experimental Sound Pressure Levels for a Torque Setting of 80 in-lb, with a .032 inch Thick Aluminum Test Panel Installed.

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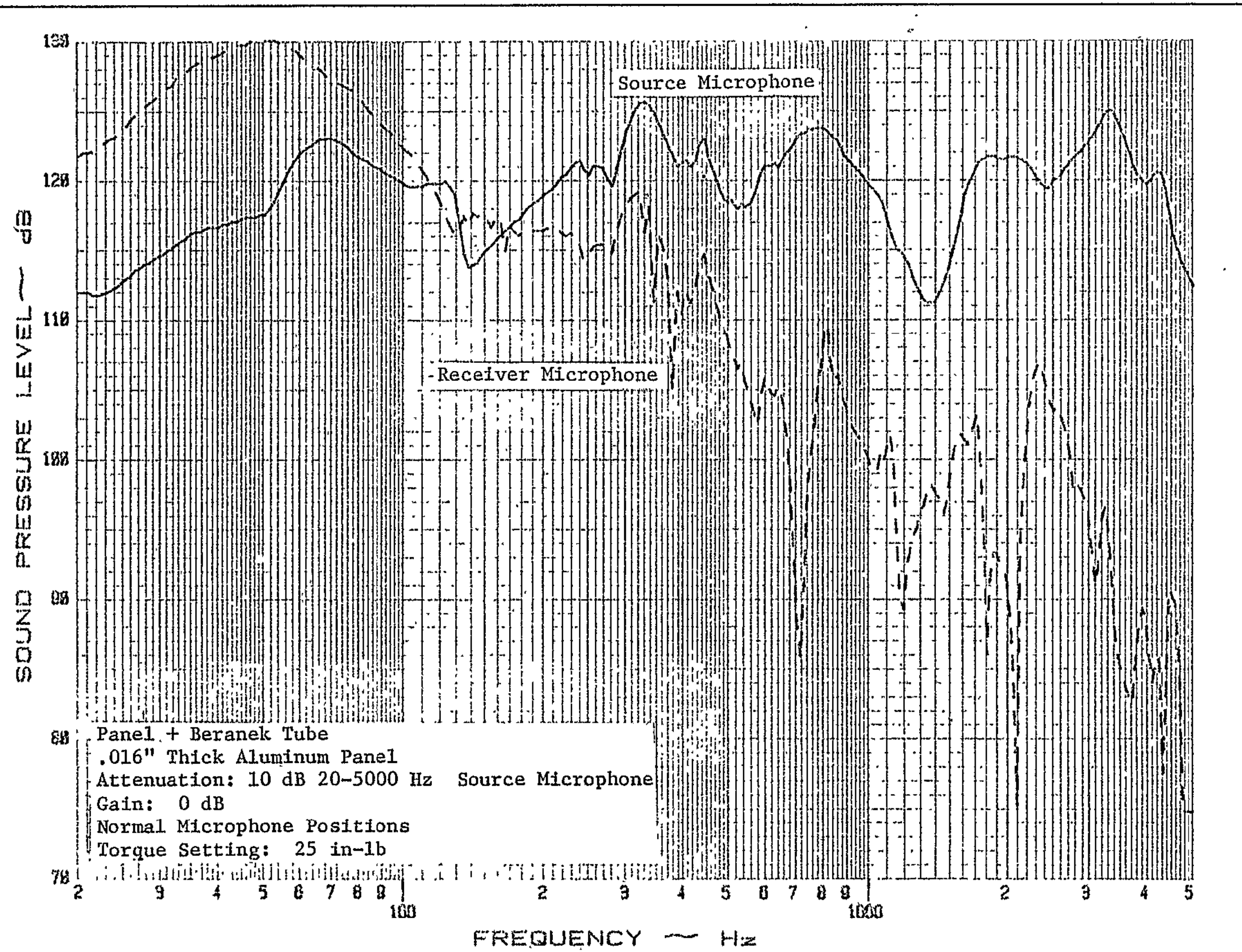

Figure 62: Experimental Sound Pressure Levels for a Torque Setting of 25 in-lb, with a .016" Thick Aluminum Test Panel Installed.

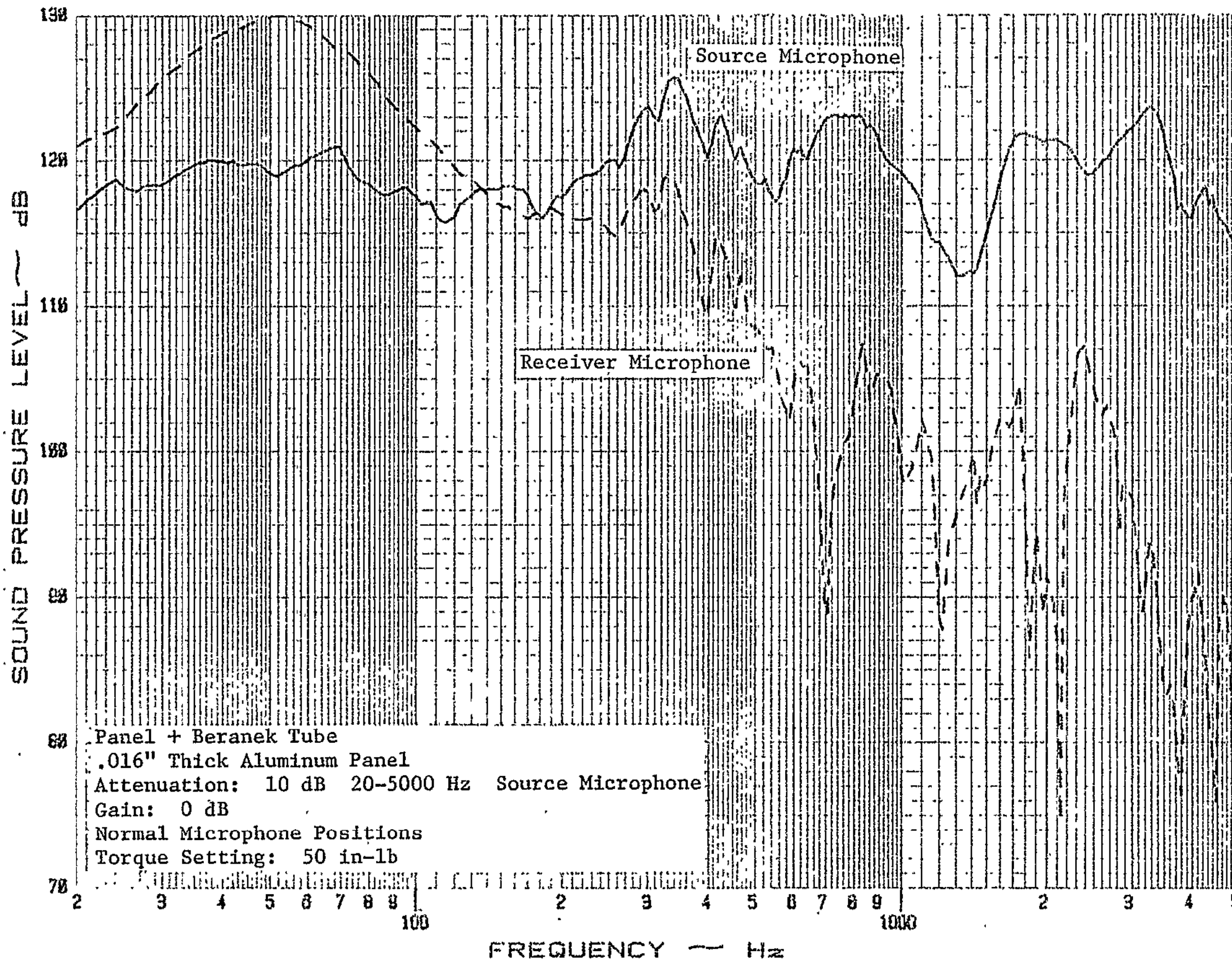

Figure 63: Experimental Sound Pressure Levels for a Torque Setting of 50 in-lb, with a .016" Thick Aluminum Panel Installed.

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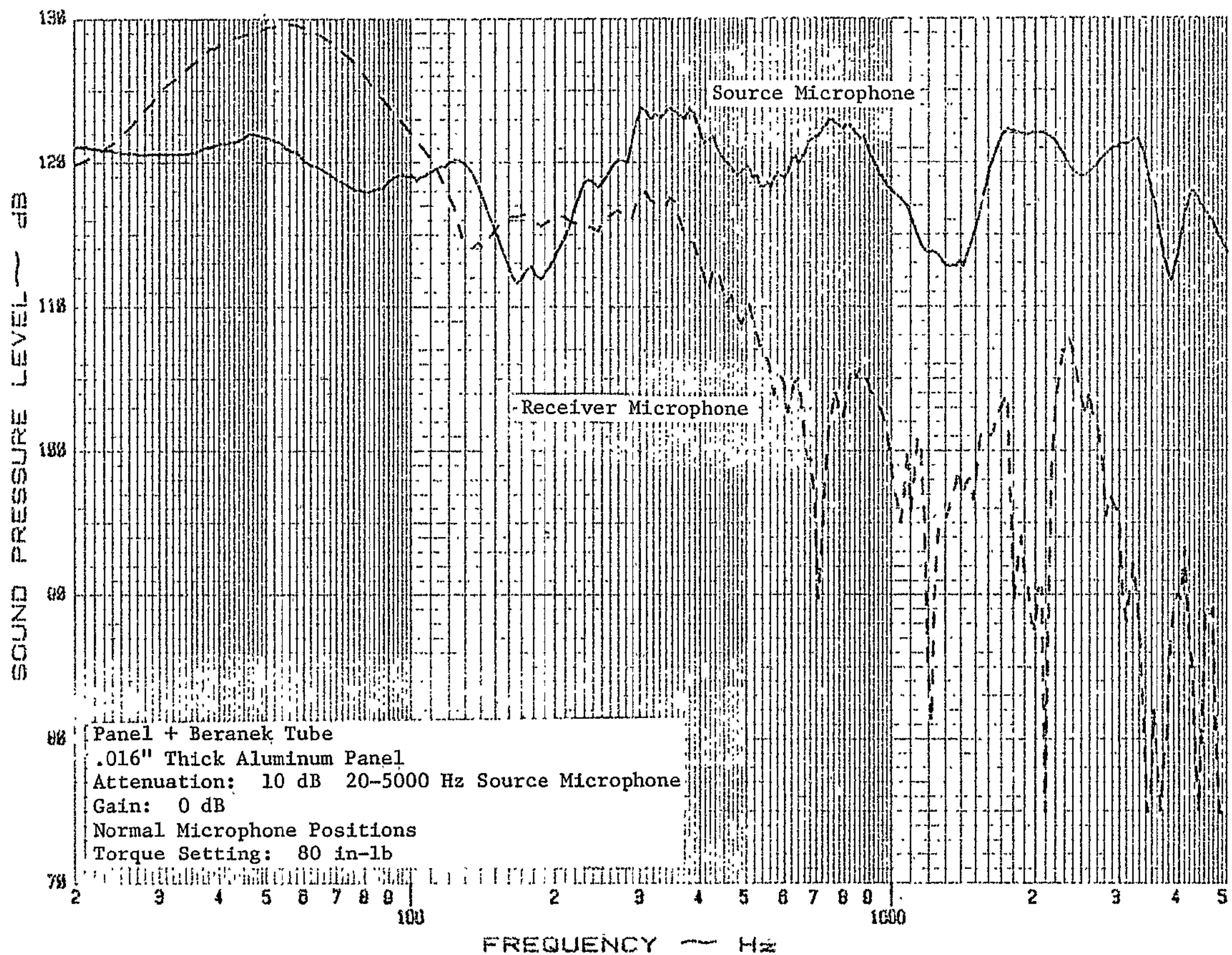

Figure 64: Experimental Sound Pressure Levels for a Torque Setting of 80 in-lb, with a .016 inch Thick Aluminum Test Panel Installed.

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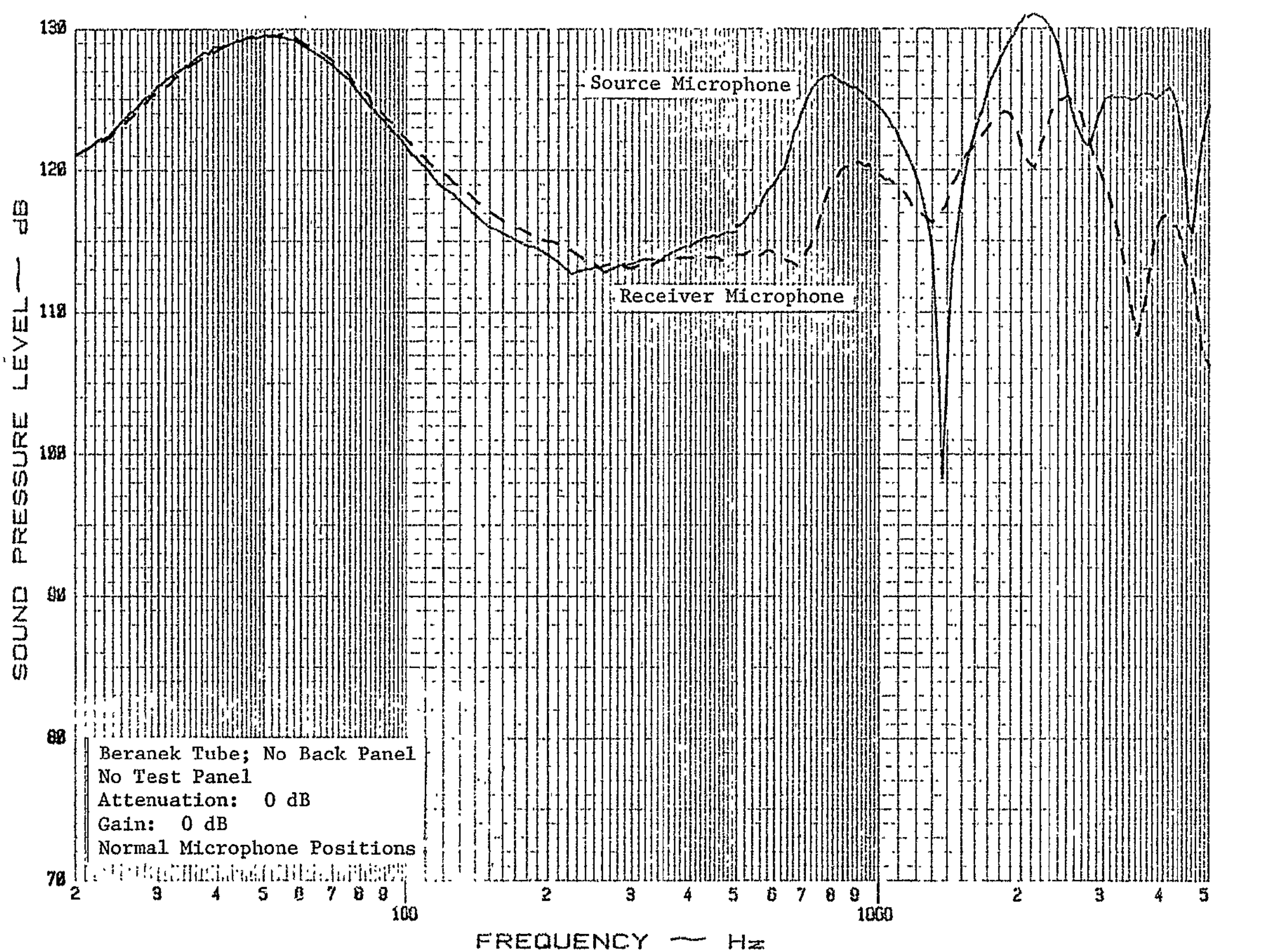

Figure 65: Experimental Sound Pressure Levels in the Beranek Tube with a Back Panel.

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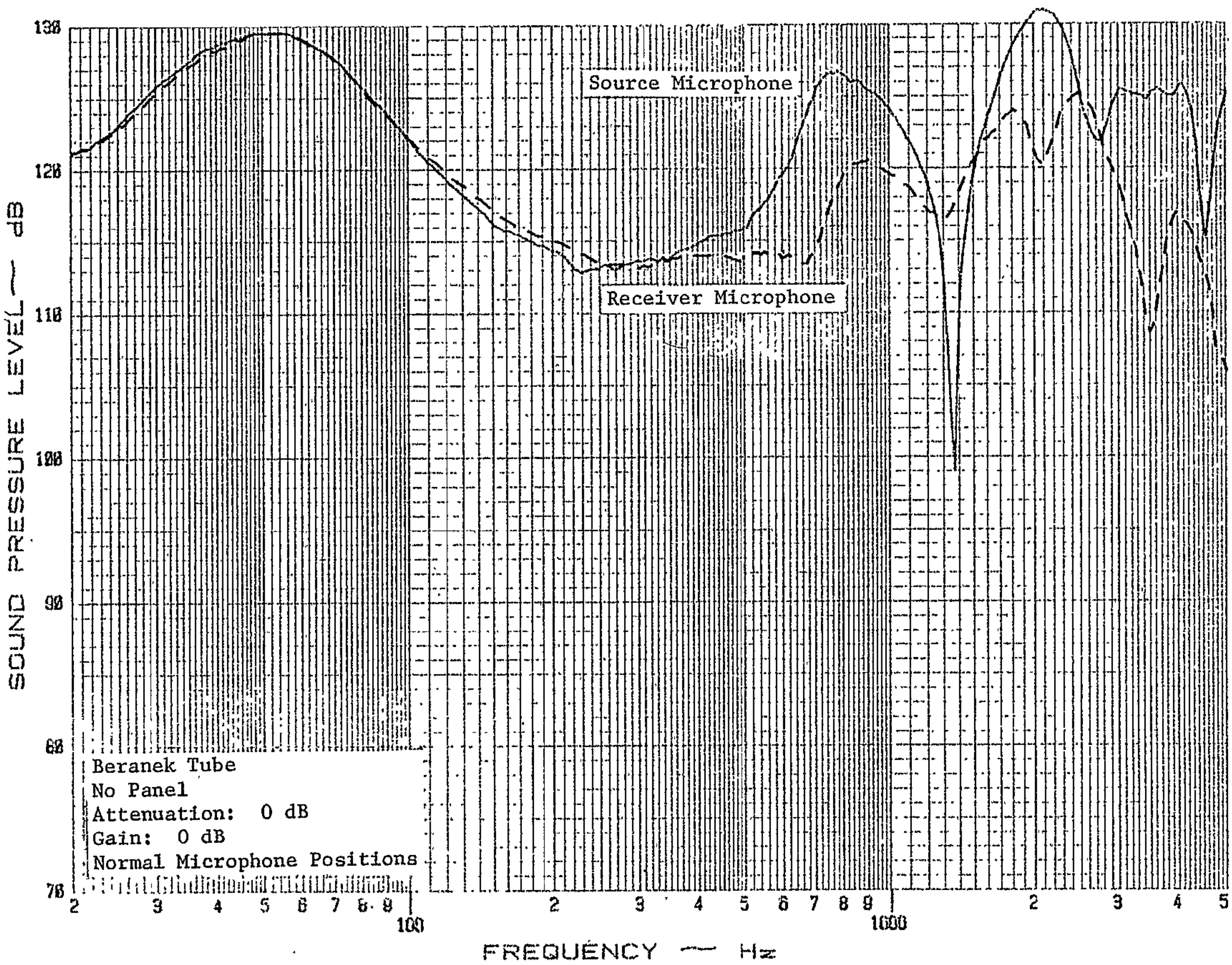

Figure 66: Experimental Sound Pressure Levels in the Beranek Tube without a Back Panel.

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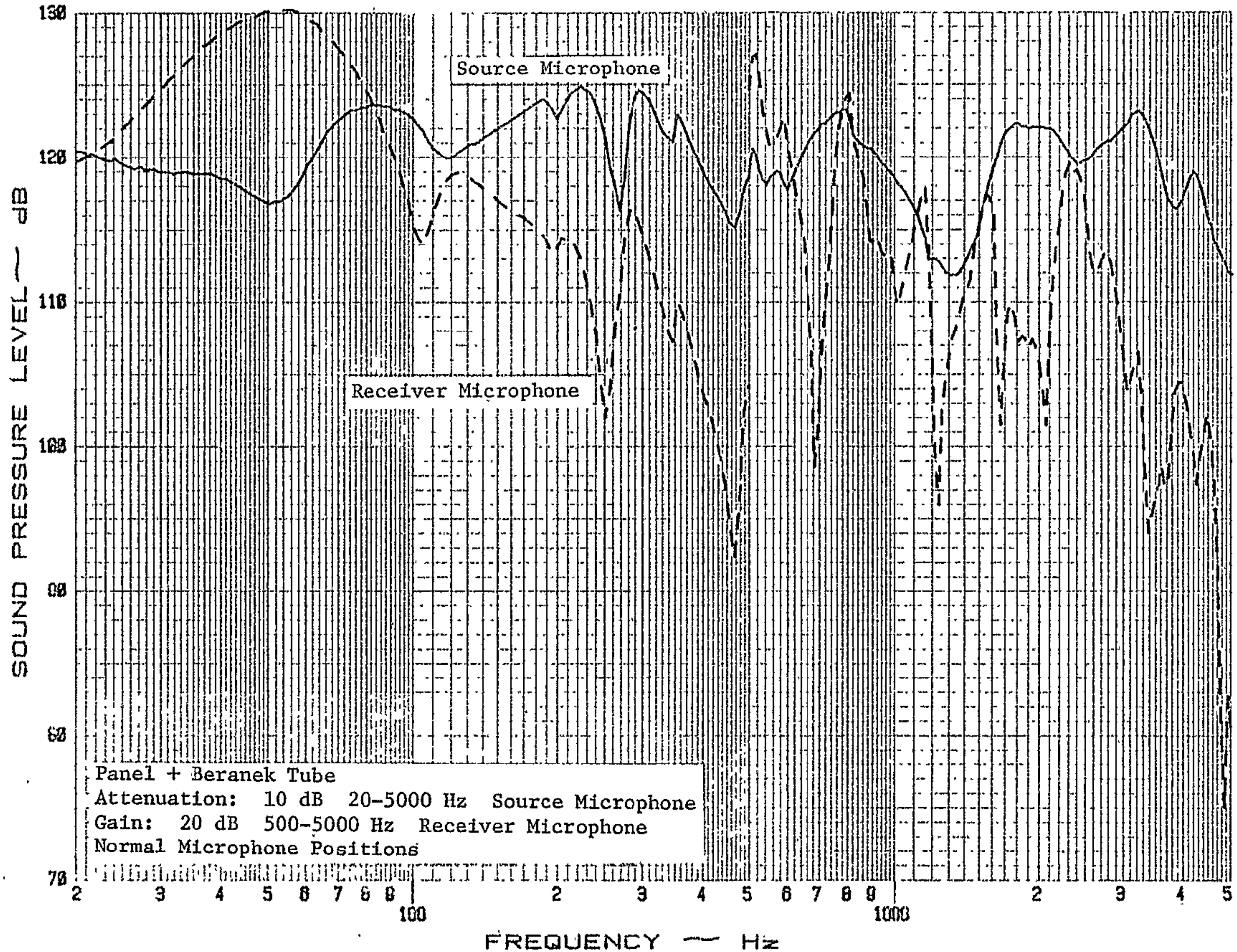

Figure 67: Experimental Sound Pressure Levels in the Beranek Tube with a Back Panel and a Test Panel Installed.

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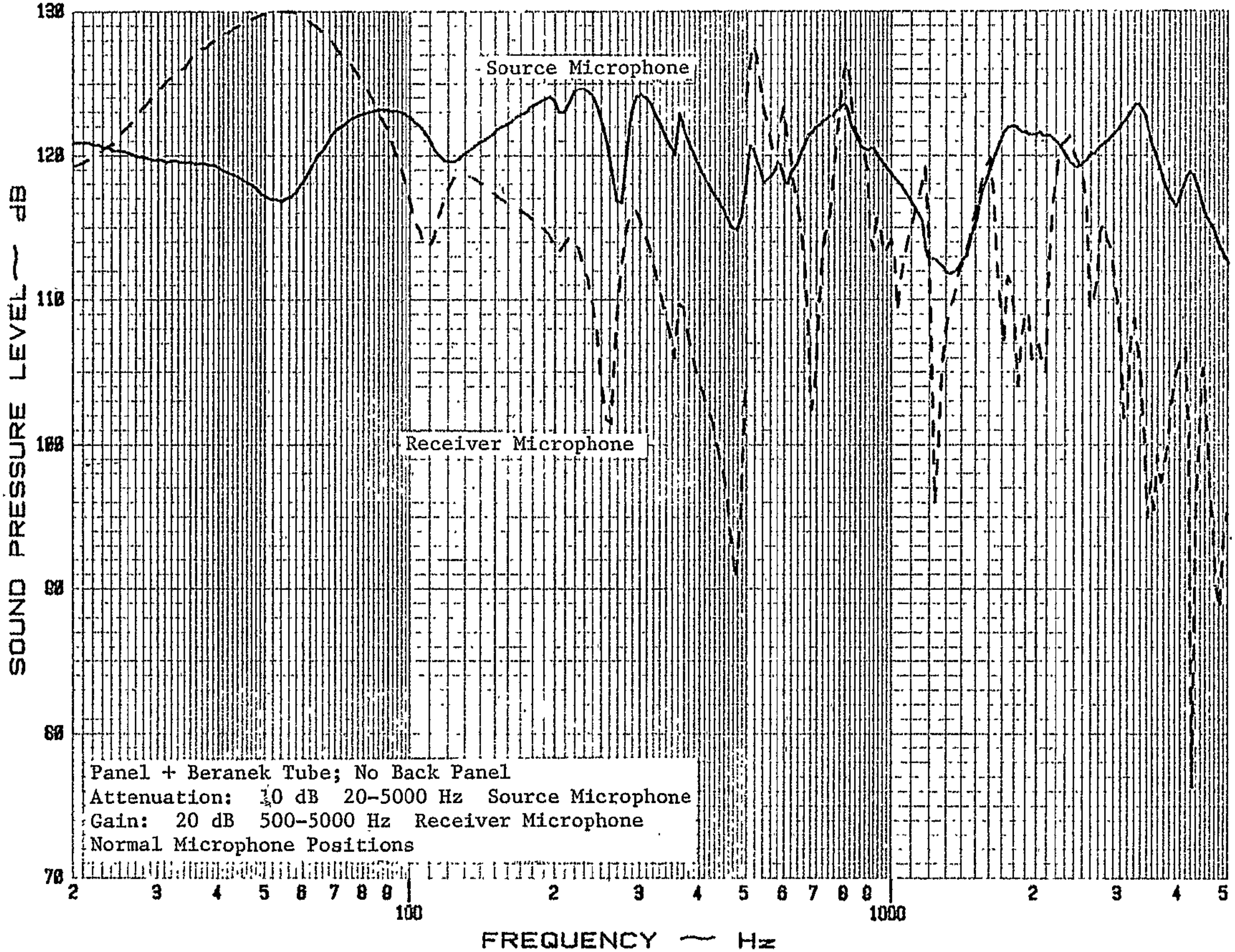

Figure 68: Experimental Sound Pressure Levels in the Beranek Tube without a Back Panel but with a Test Panel Installed.

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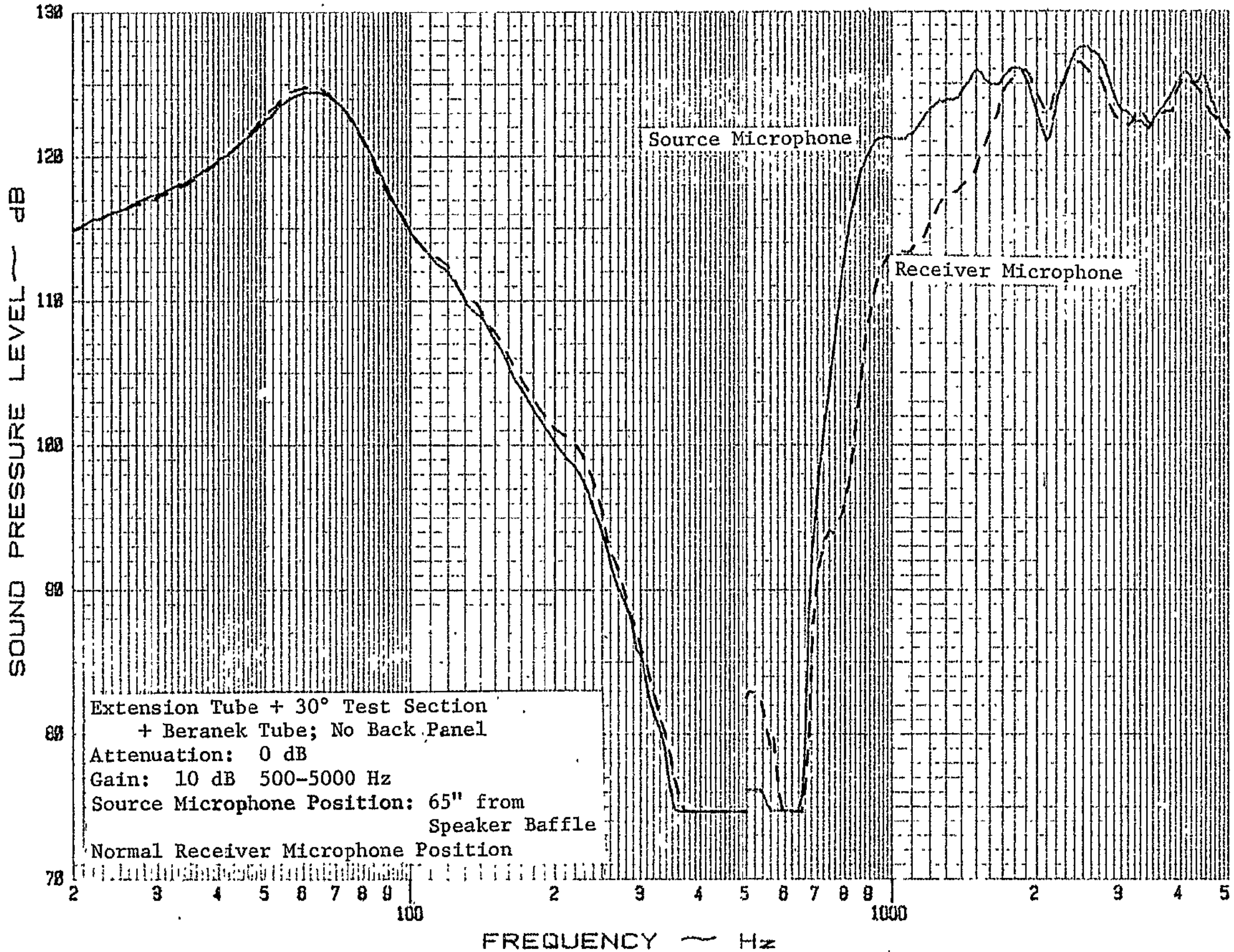

Figure 69: Experimental Sound Pressure Levels for a Source Microphone Position at a Distance of 65" from the Speaker Baffle and a Normal Receiver Microphone Position without a Beranek Tube Back Panel.

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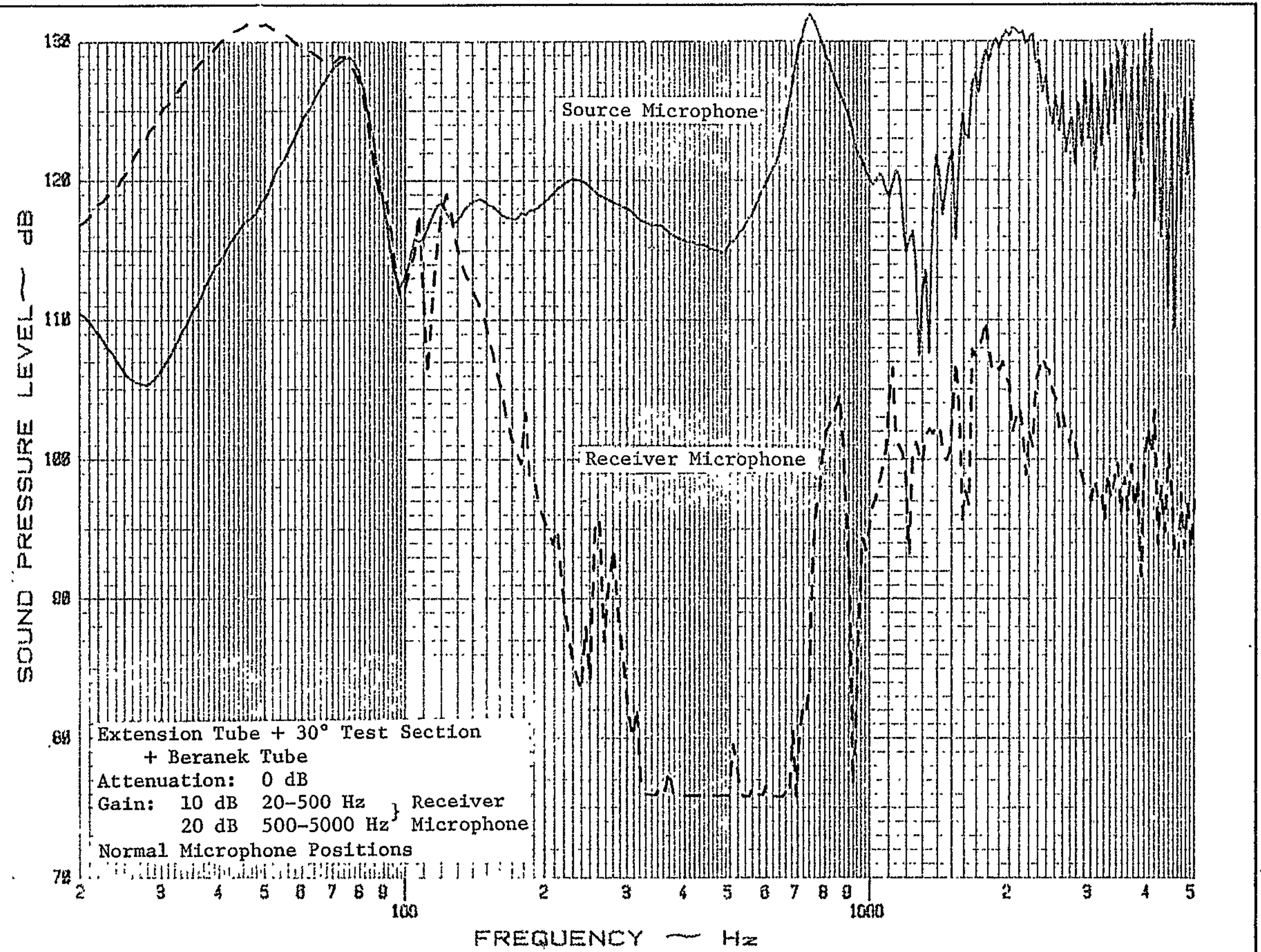

Figure 70: Experimental Sound Pressure Levels for the Normal Source and Normal Receiver Microphone Positions Using the Configuration of Figure 1c.

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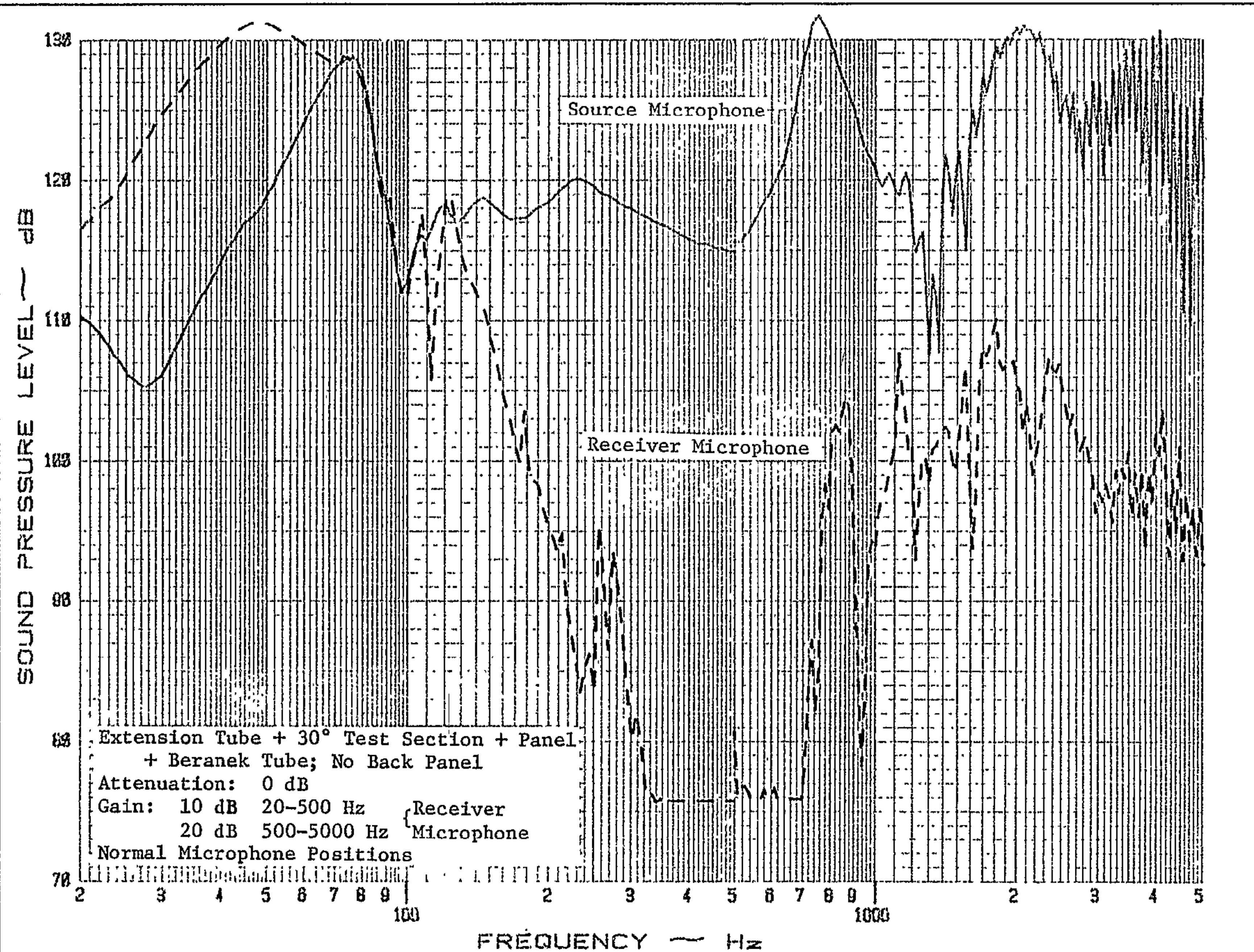

Figure 71: Experimental Sound Pressure Levels for the Normal Source and Normal Receiver Microphone Positions, Using the Configuration of Figure 1c, without the Back Panel of the Beranek Tube.

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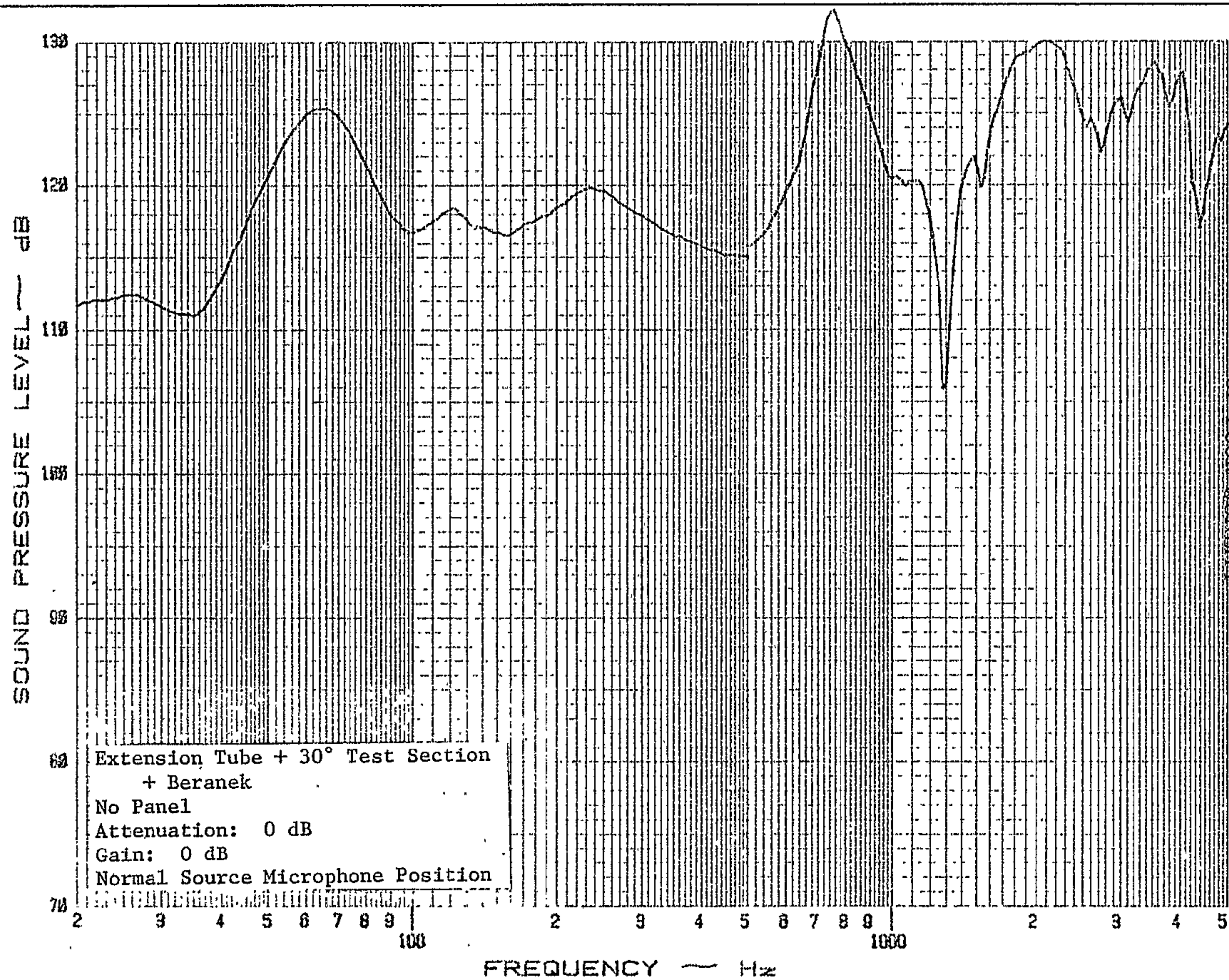

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Figure 72: Experimental Sound Pressure Level for the Normal Source Microphone Position.

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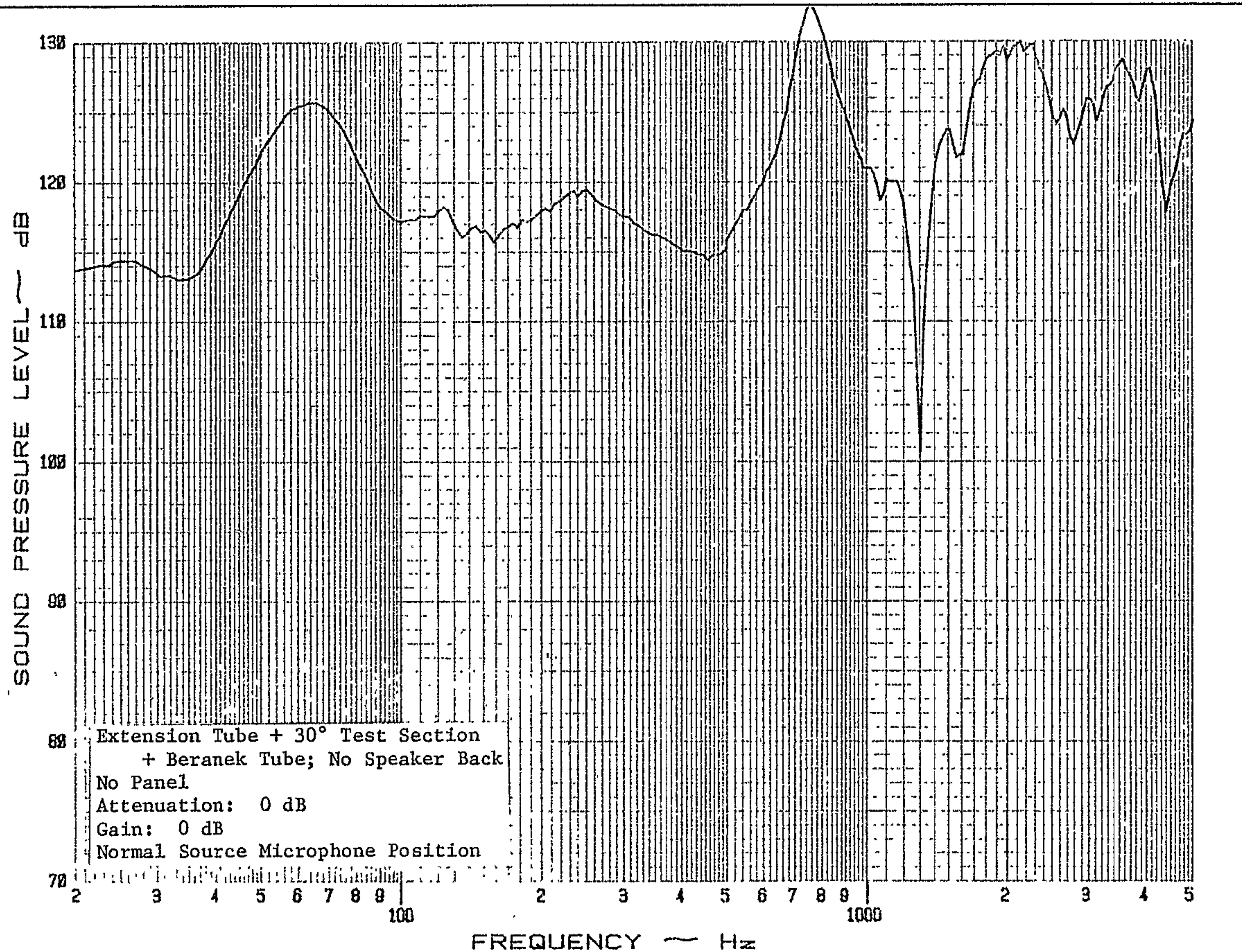

Figure 73: Experimental Sound Pressure Level for the Normal Source Microphone Position without the Speaker Back Panel.

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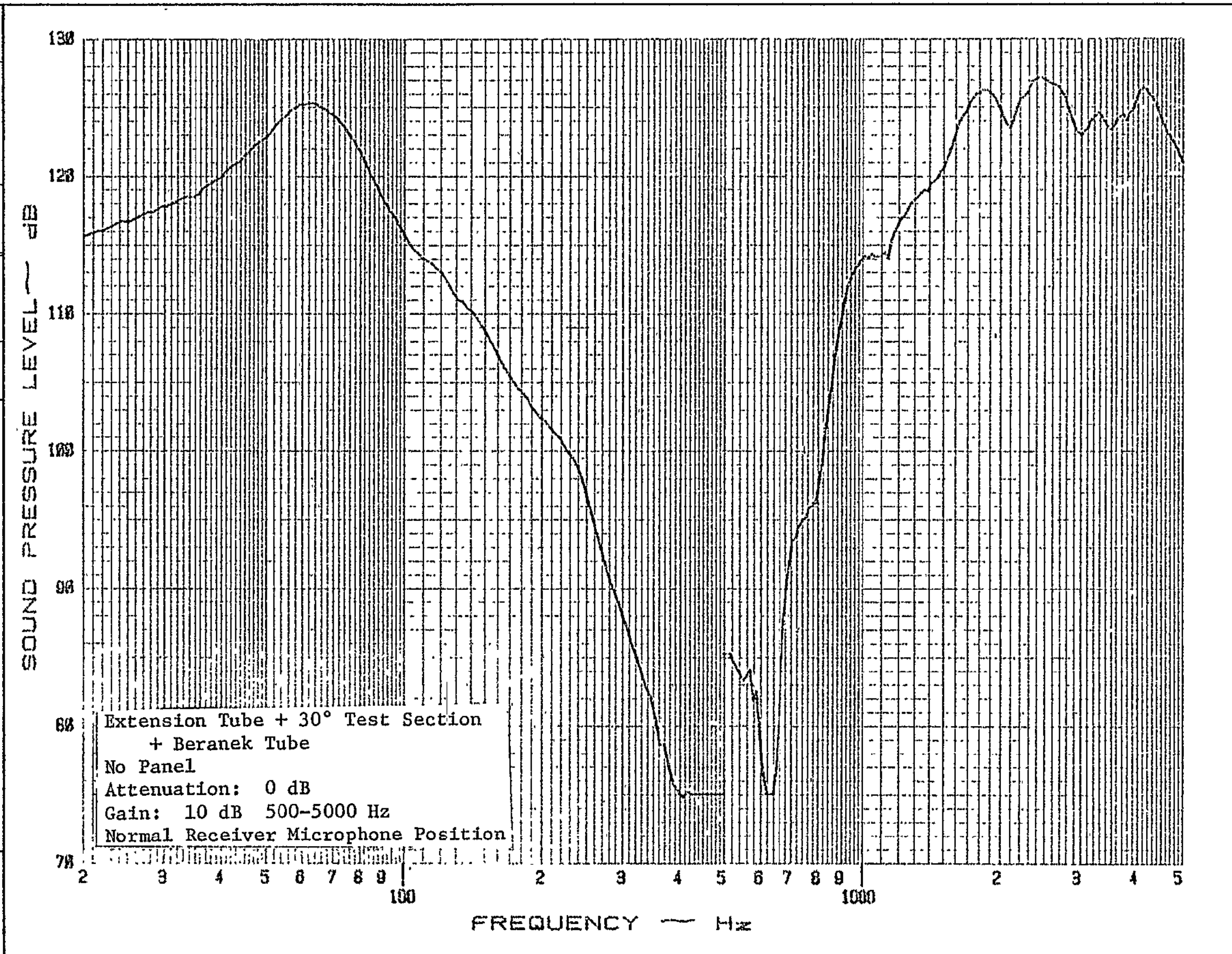

Figure 74: Experimental Sound Pressure Level for the Normal Receiver Microphone Position.

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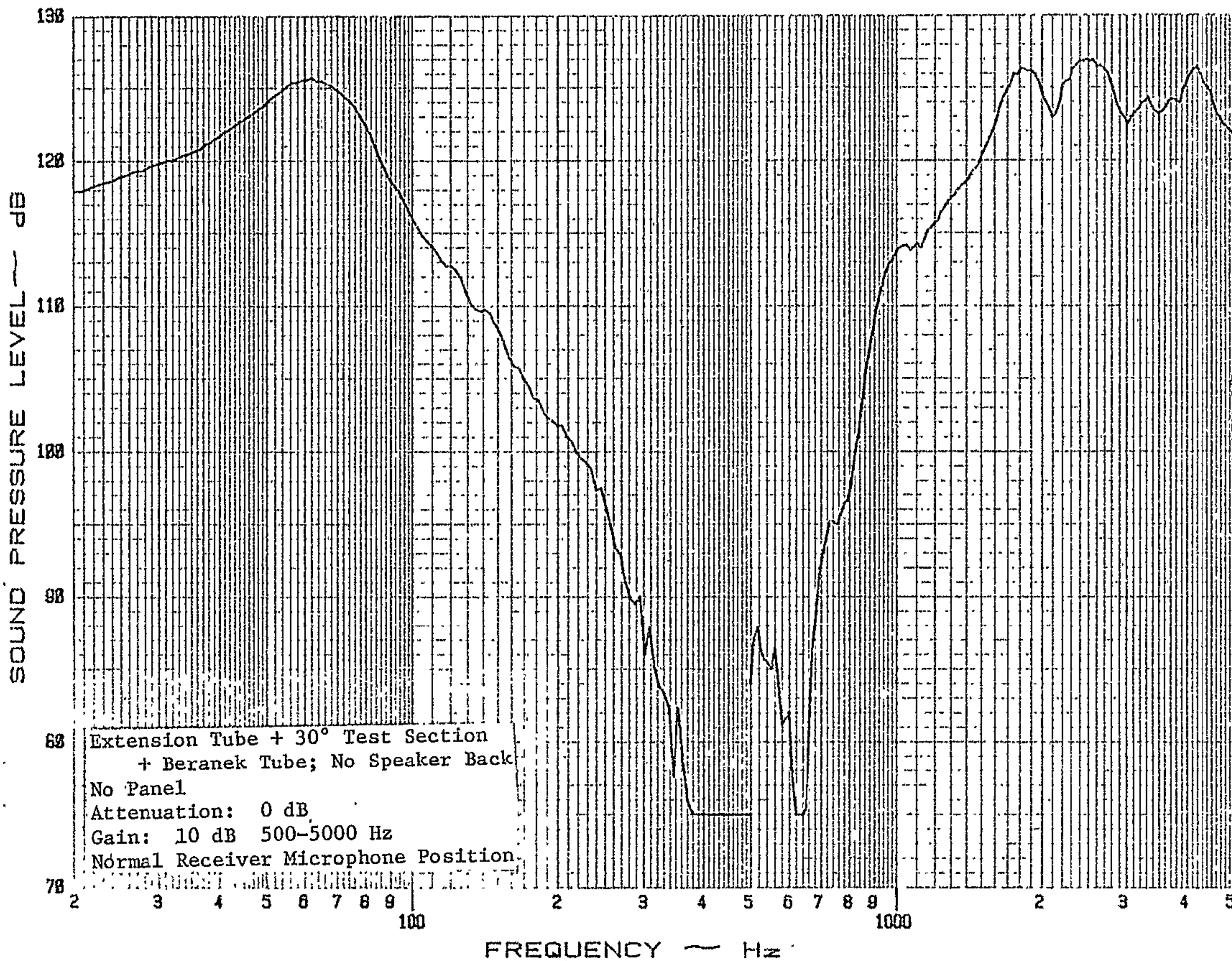

Figure 75: Experimental Sound Pressure Level for the Normal Receiver Microphone Position without the Speaker Back Panel.

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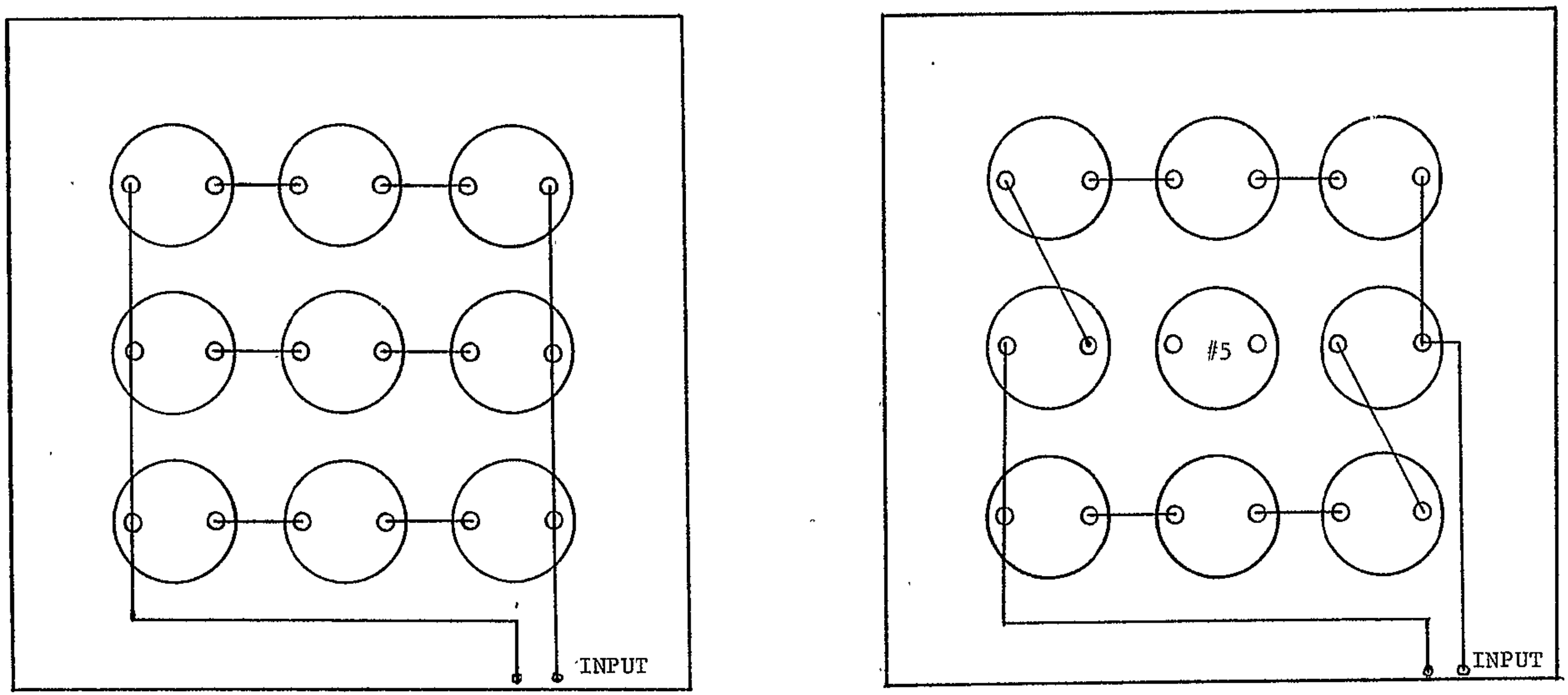

Figure 76: Scheme of the Electric Wiring if All Nine Speakers Are Connected and When Speaker #5 Is Disconnected.

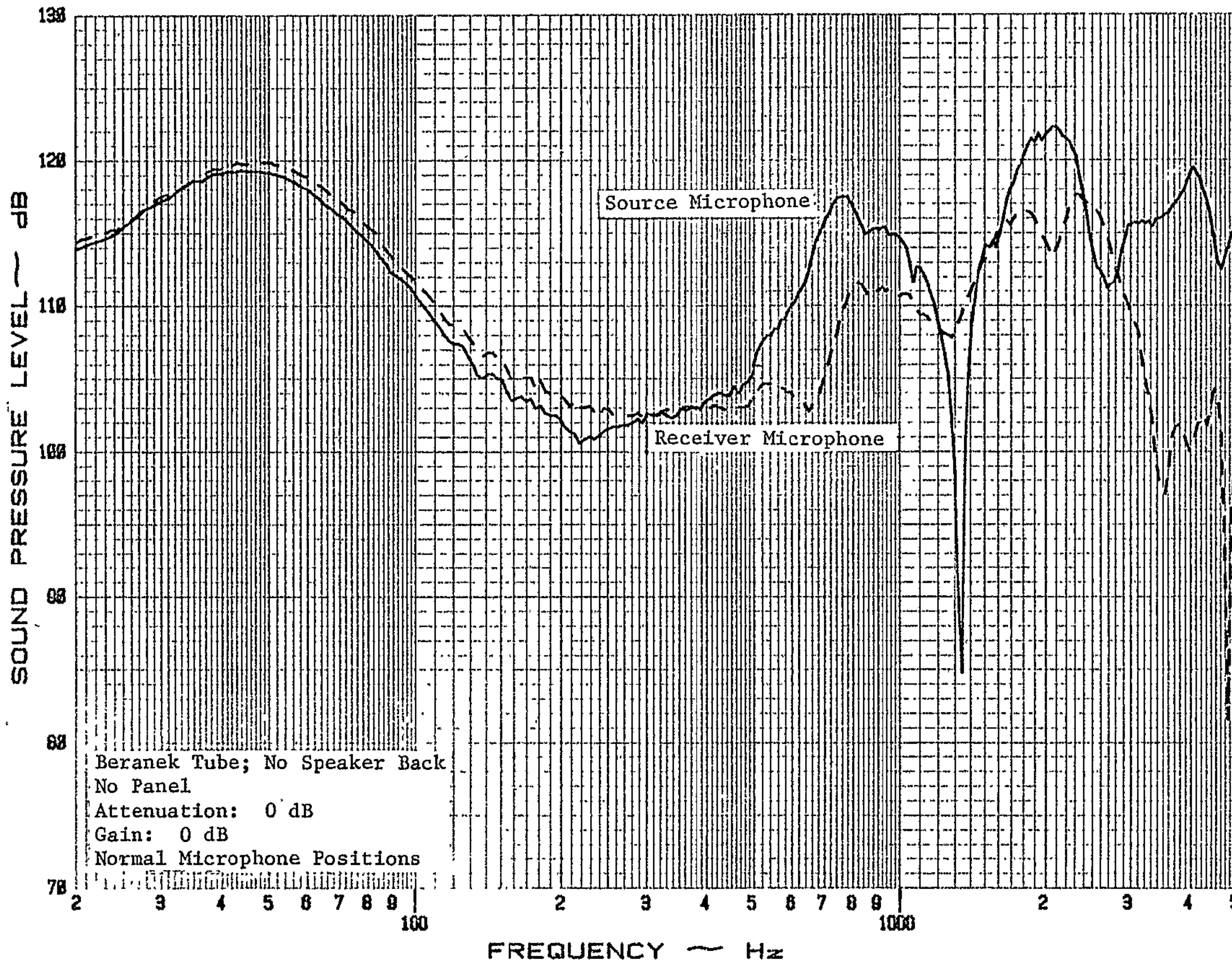

Figure 77: Experimental Sound Pressure Levels with All Nine Speakers Connected and without a Speaker Back Panel.

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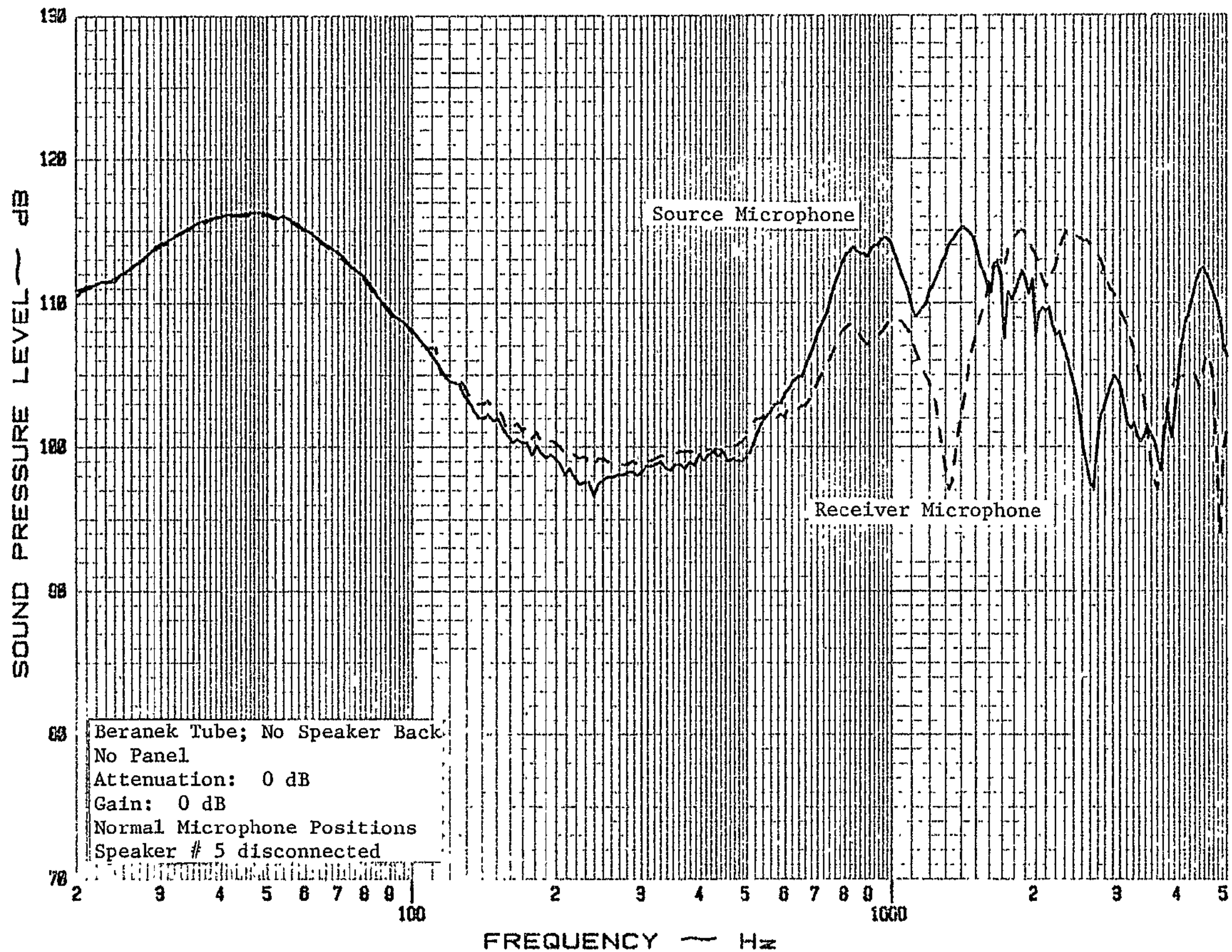

Figure 78: Experimental Sound Pressure Levels, Speaker #5 Disconnected and without a Speaker Back Panel.

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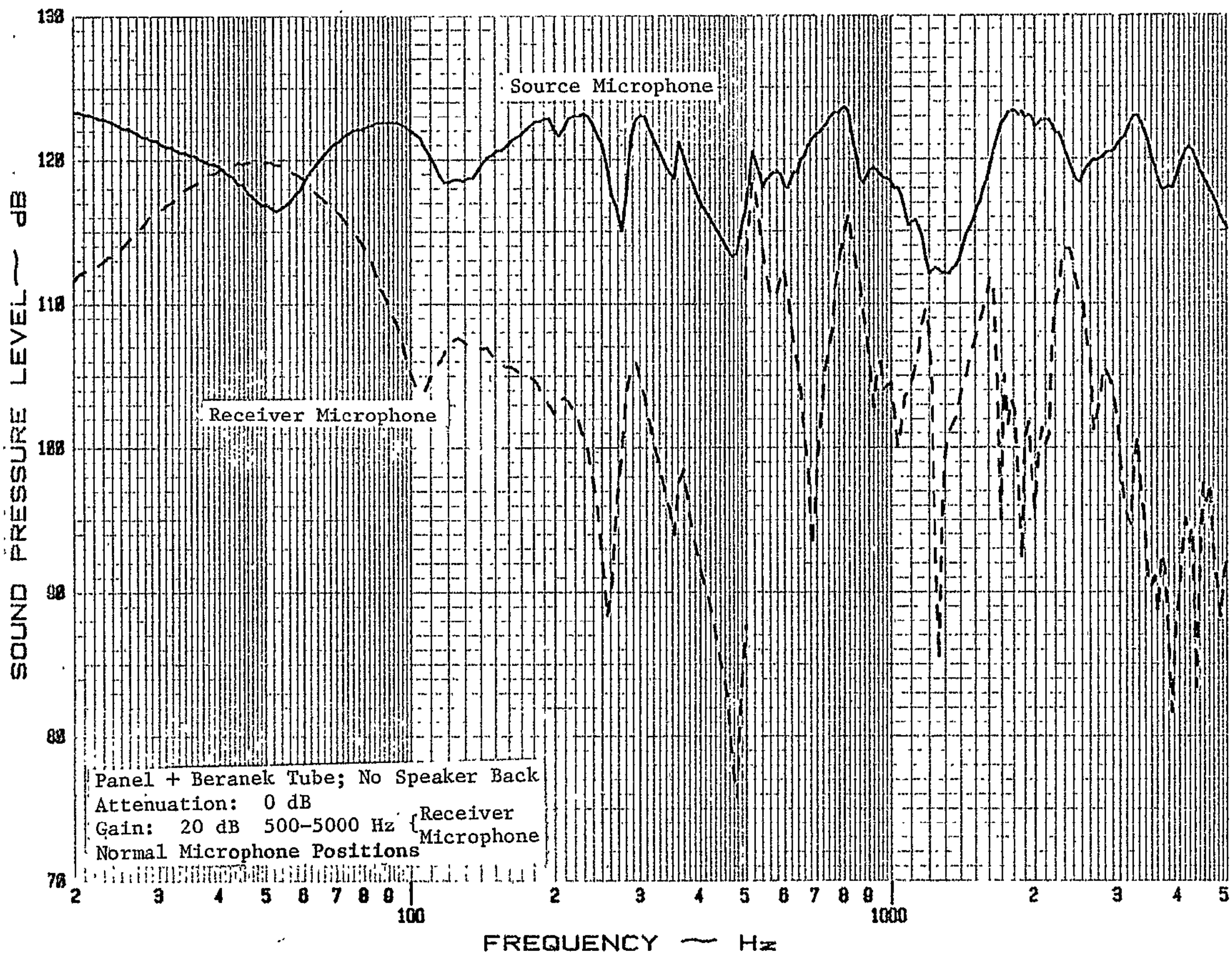

Figure 79: Experimental Sound Pressure Levels with All Nine Speakers Connected and a Test Panel Installed.

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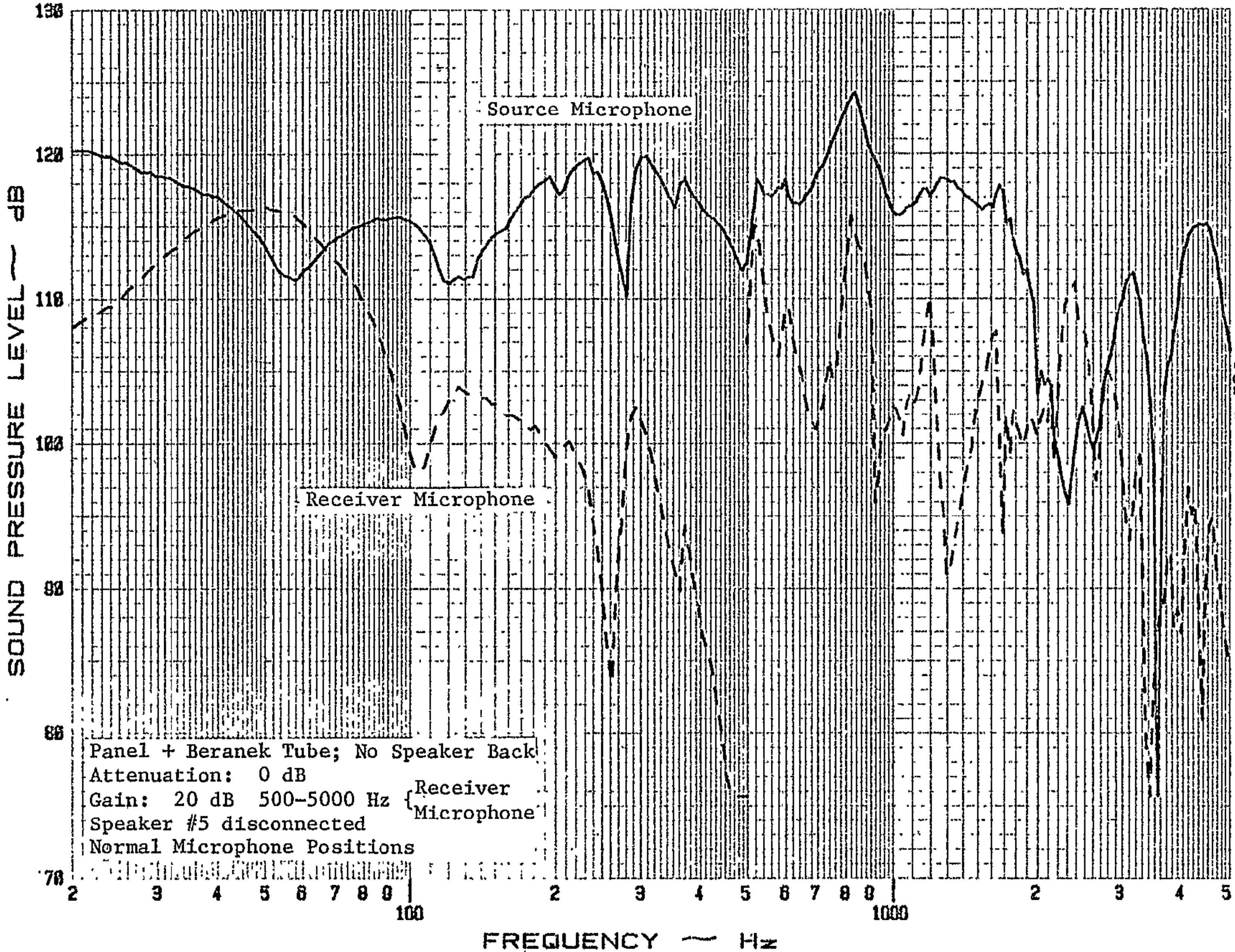

Figure 80: Experimental Sound Pressure Levels, Speaker #5 Disconnected and a Test Panel Installed.

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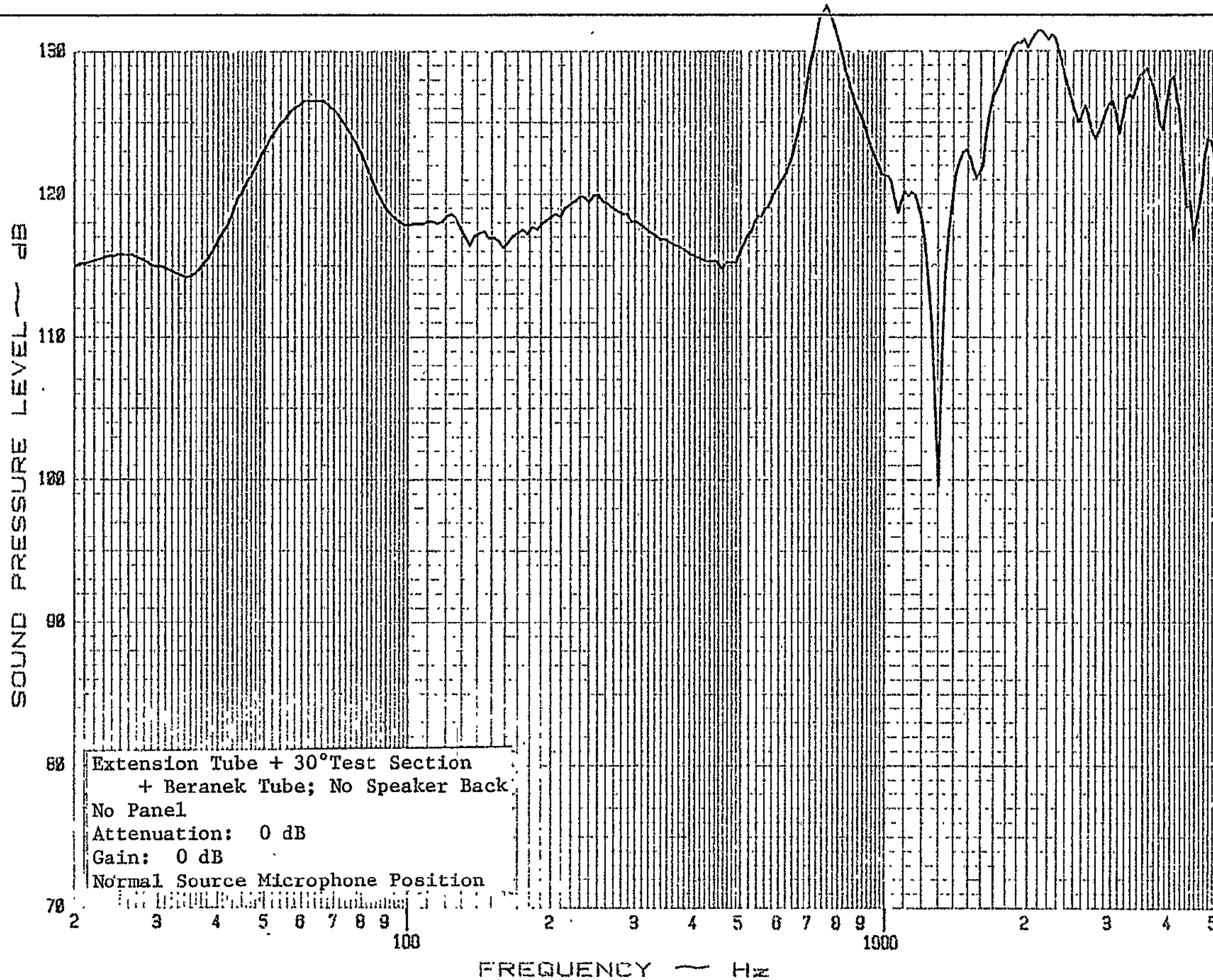

Figure 81: Experimental Sound Pressure Level for the Normal Source Microphone Position and All Nine Speakers Connected.

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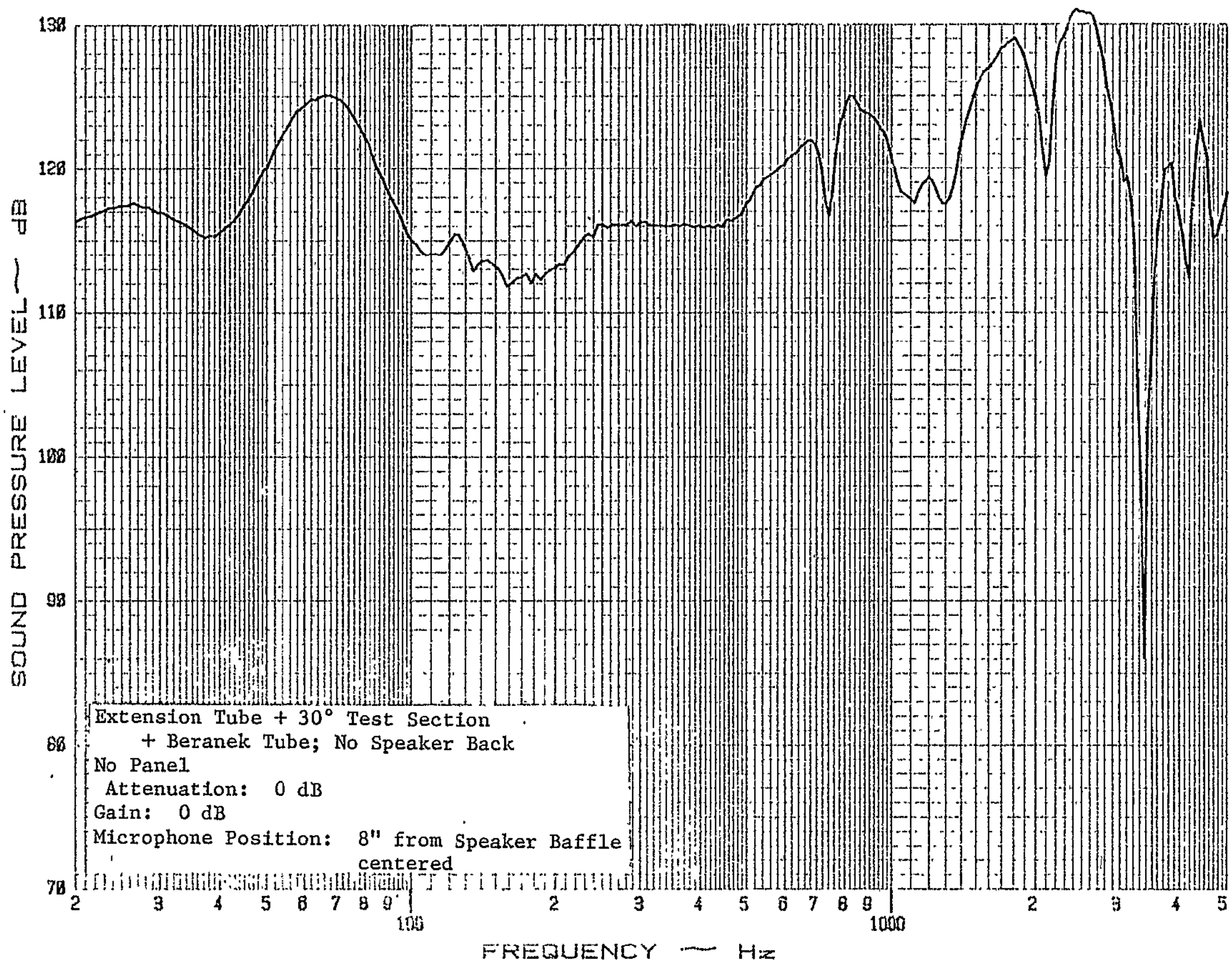

Figure 82: Experimental Sound Pressure Level for a Microphone Position at a Distance of 8" from the Speaker Baffle and All Nine Speakers Connected.

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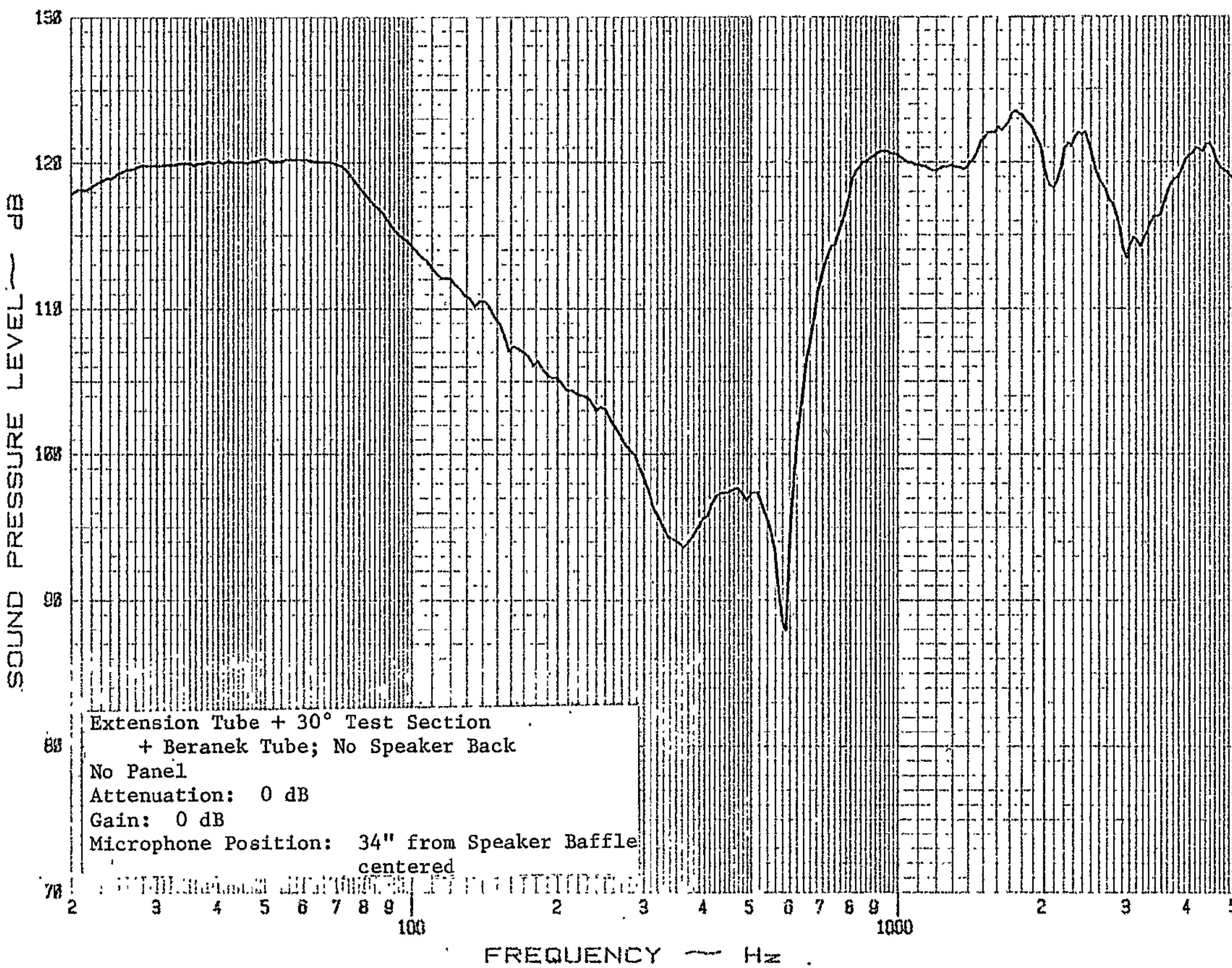

Figure 83: Experimental Sound Pressure Level for a Microphone Position at a Distance of 34" from the Speaker Baffle and All Nine Speakers Connected.

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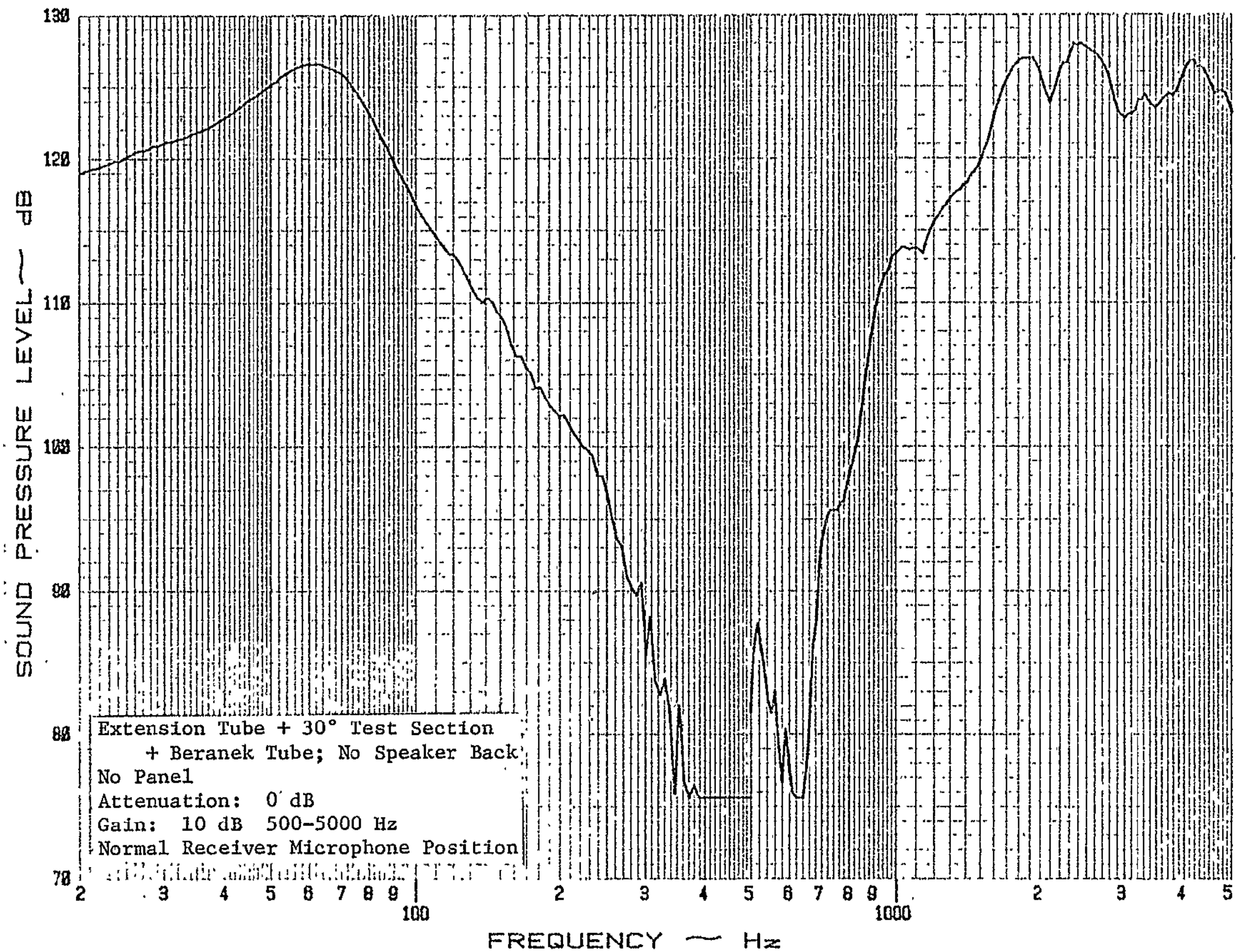

Figure 84: Experimental Sound Pressure Level for the Normal Receiver Microphone Position and All Nine Speakers Connected.

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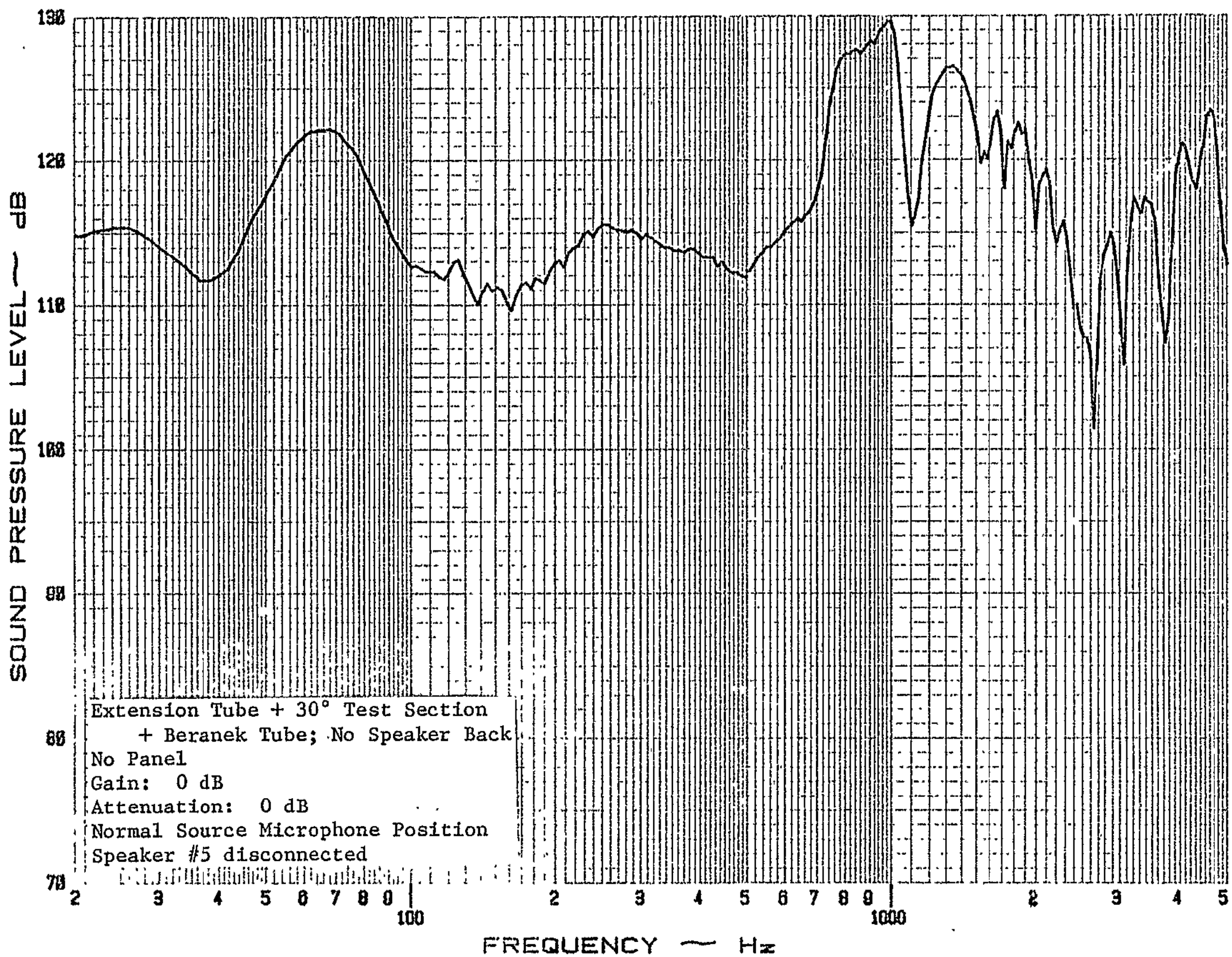

Figure 85: Experimental Sound Pressure Level for the Normal Source Microphone Position, Speaker #5 - Disconnected.

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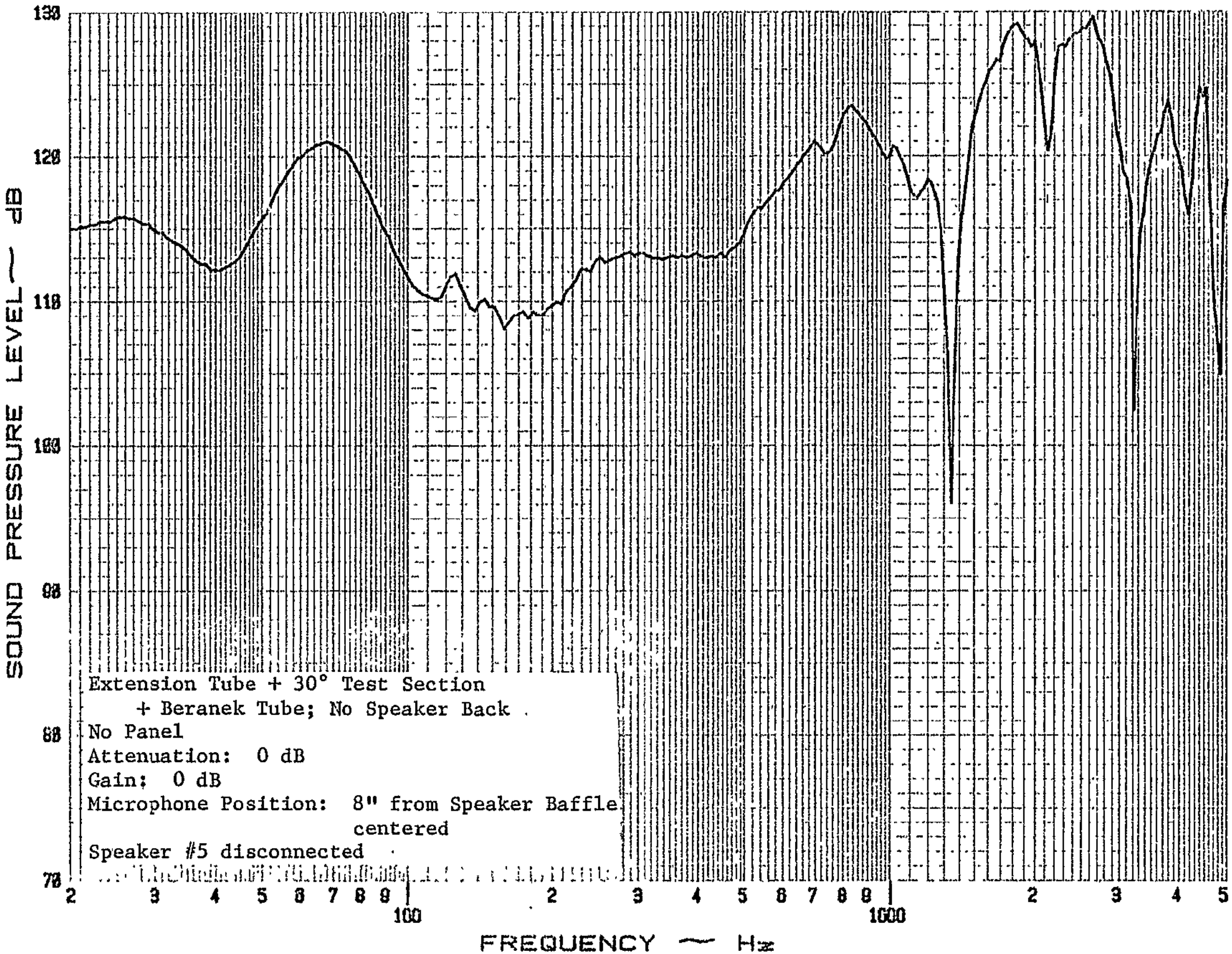

Figure 86: Experimental Sound Pressure Level for a Microphone Position at a Distance of 8" from the Speaker Baffle, Speaker #5 Disconnected.

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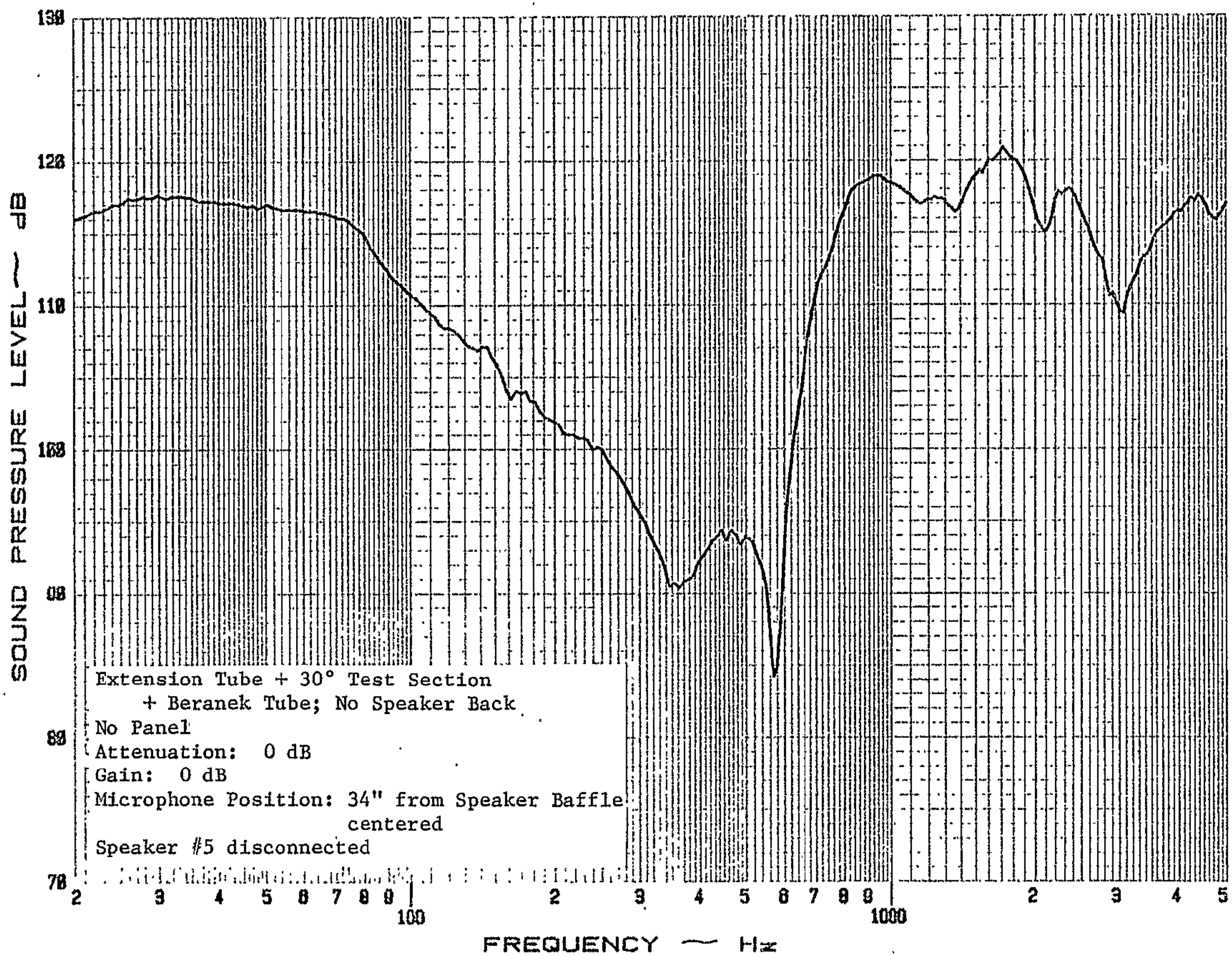

Figure 87: Experimental Sound Pressure Level for a Microphone Position at a Distance of 34" from the Speaker Baffle, Speaker #5 Disconnected.

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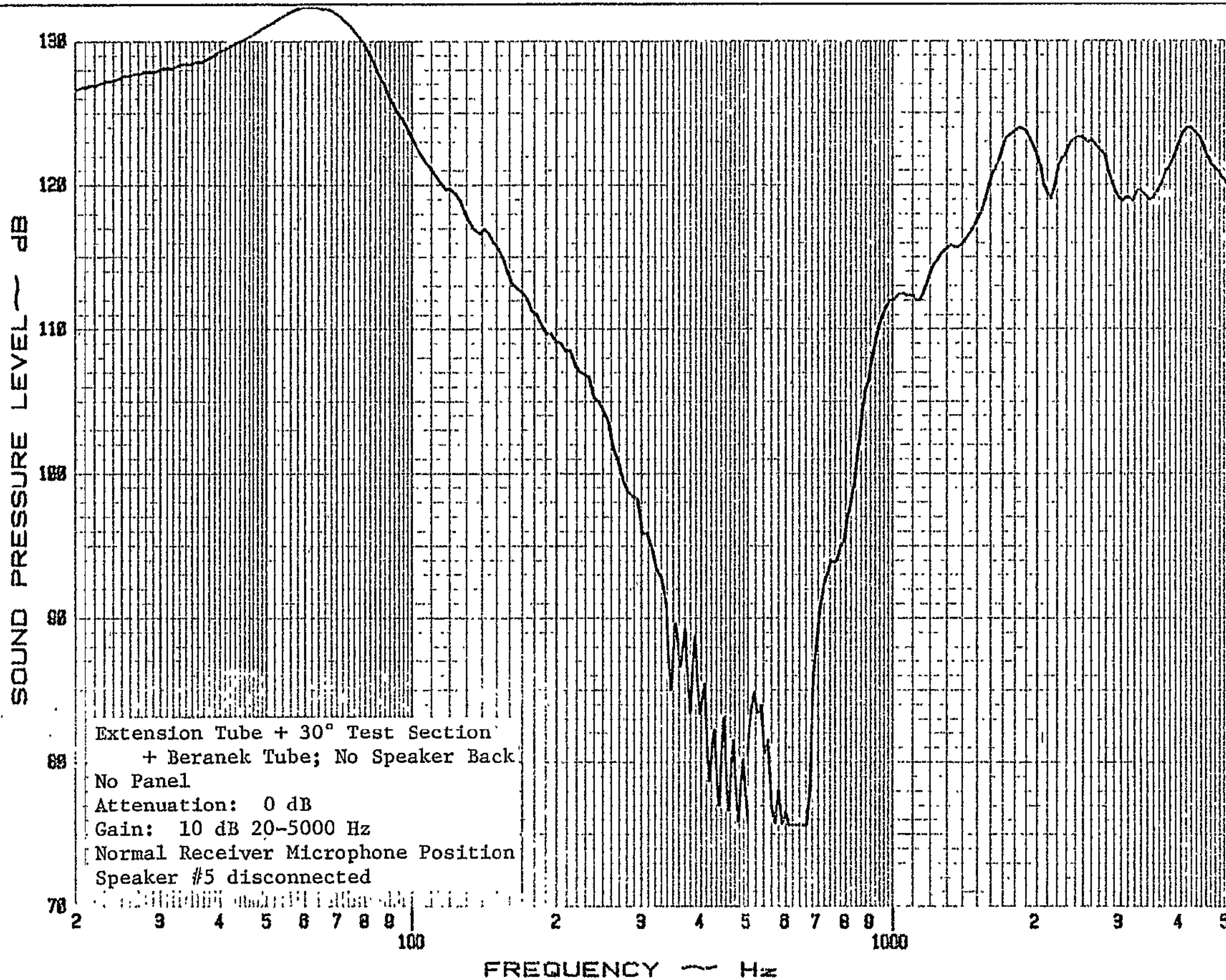

Figure 88: Experimental Sound Pressure Level for the Normal Receiver Microphone Position, Speaker #5 Disconnected.

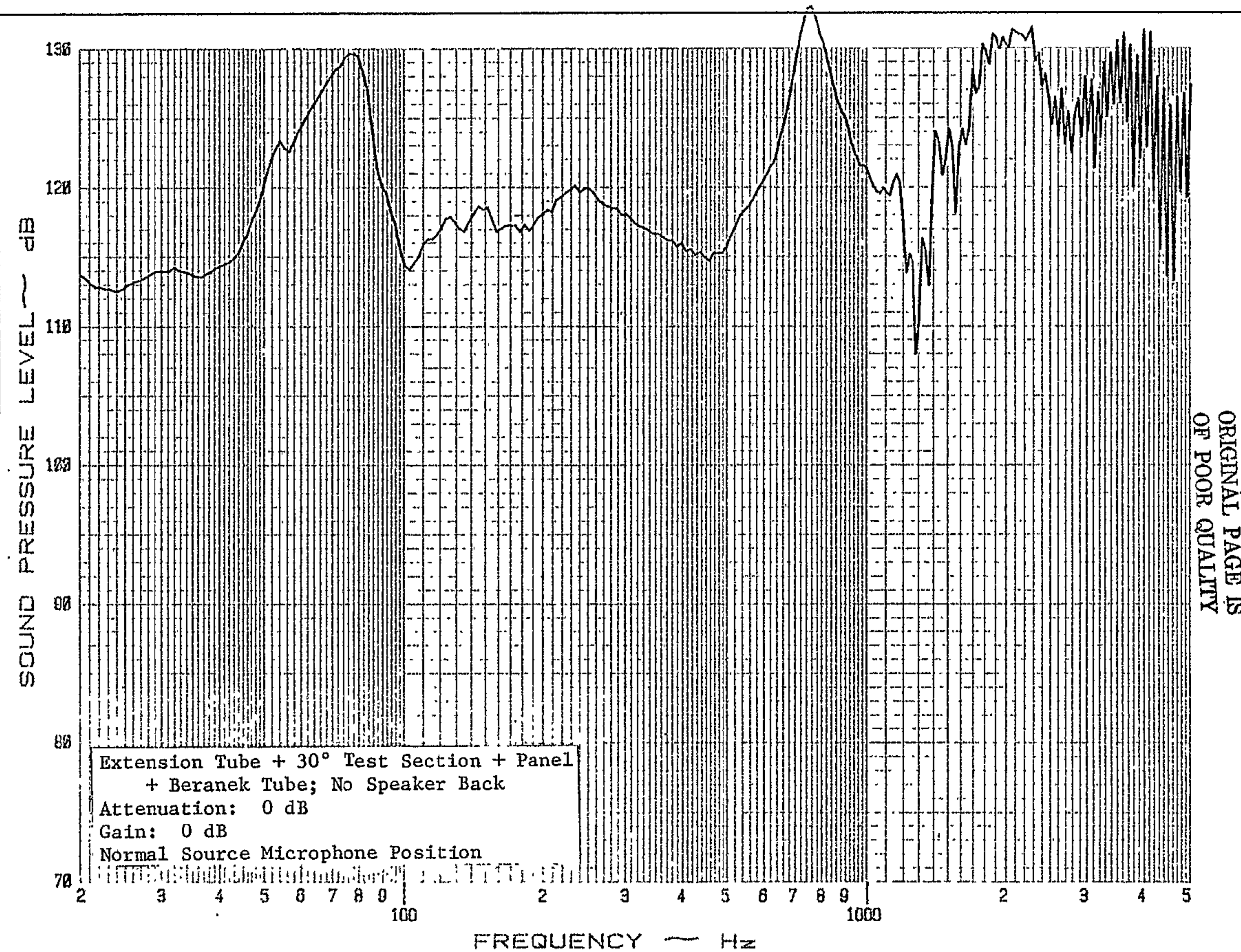

Figure 89: Experimental Sound Pressure Level for the Normal Source Microphone Position and with a Test Panel Installed.

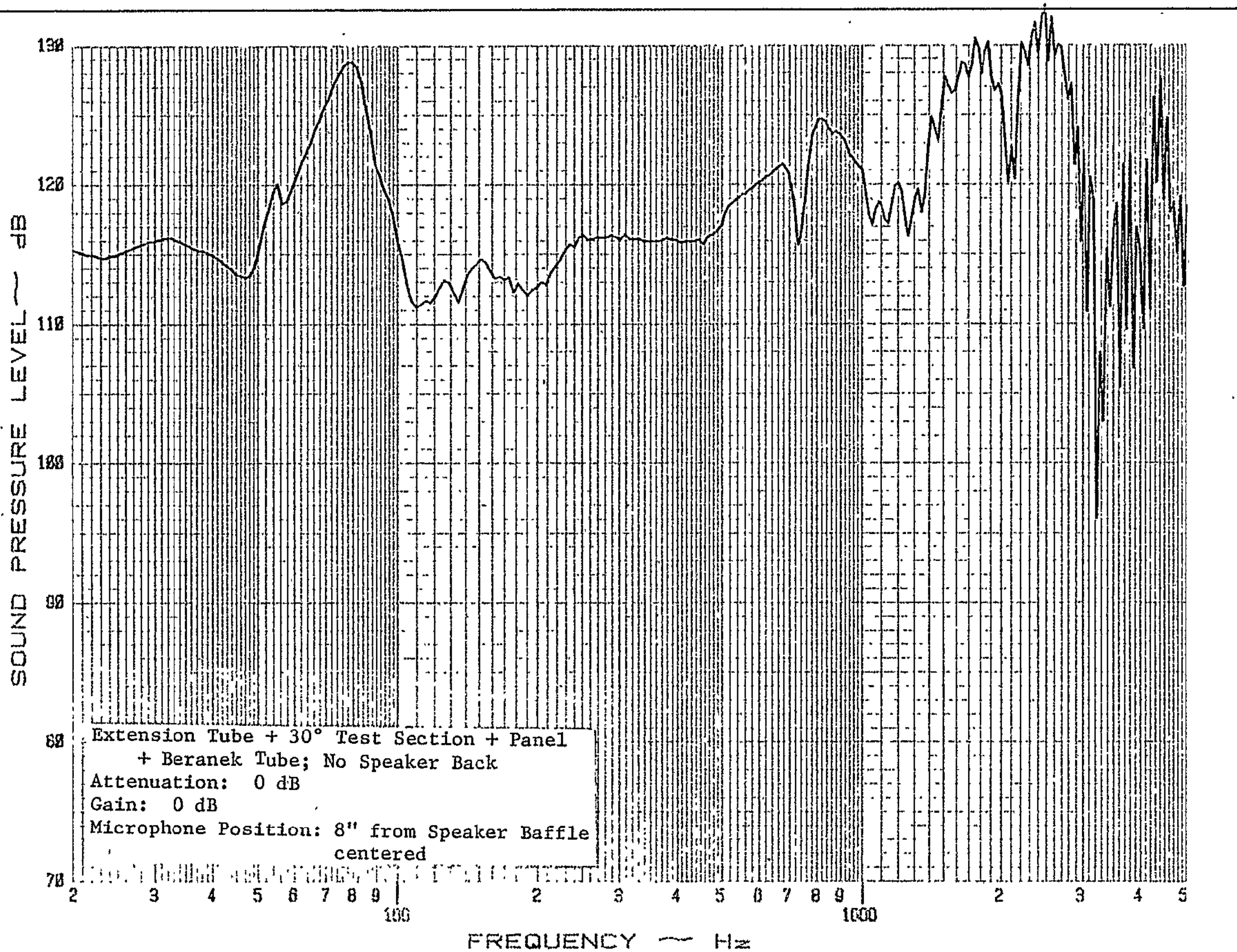

Figure 90: Experimental Sound Pressure Level for a Microphone Position at a Distance of 8" from the Speaker Baffle and with a Test Panel Installed.

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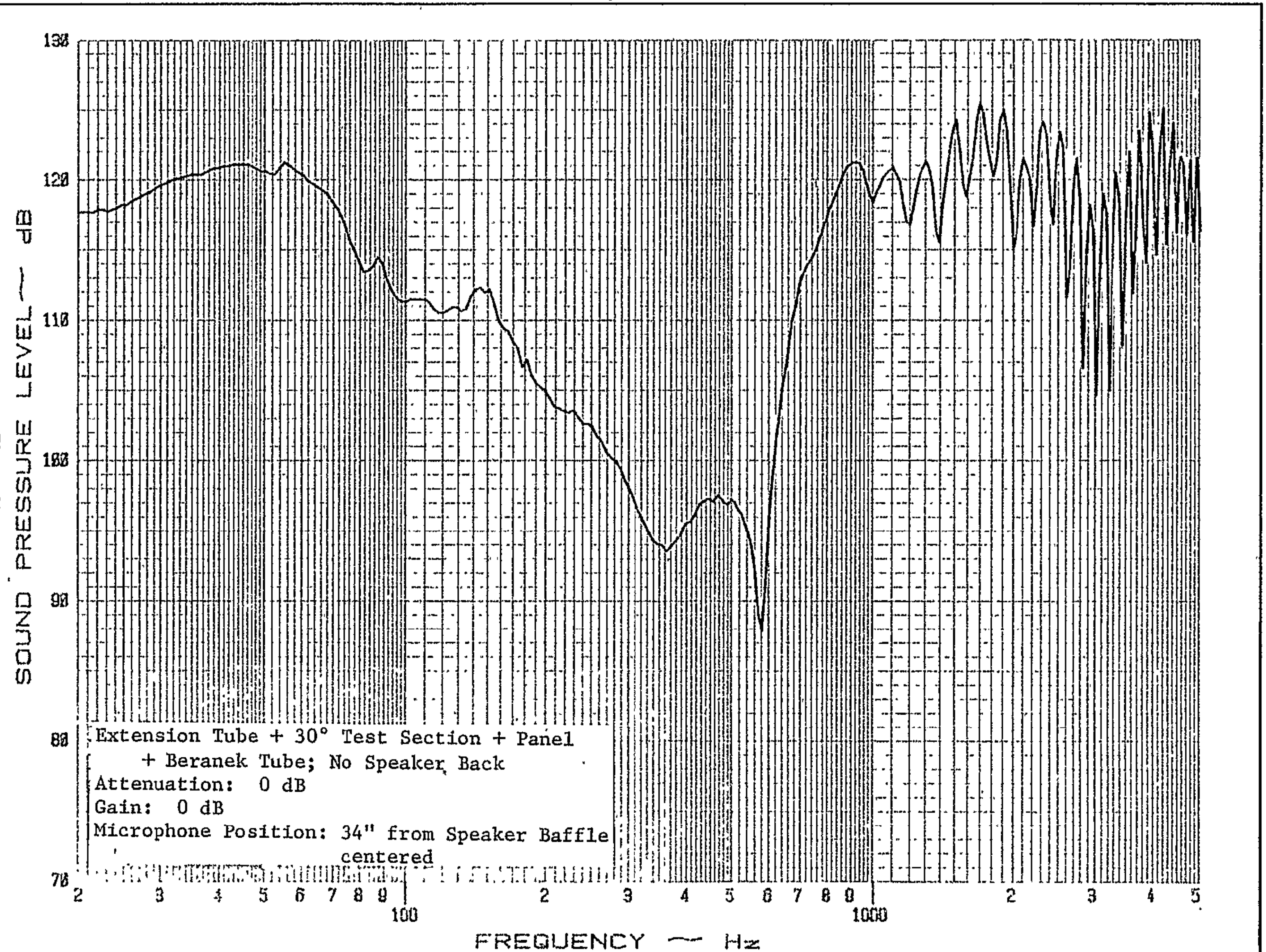

Figure 91: Experimental Sound Pressure Level for a Microphone Position at a Distance of 34" from the Speaker Baffle and with a Test Panel Installed.

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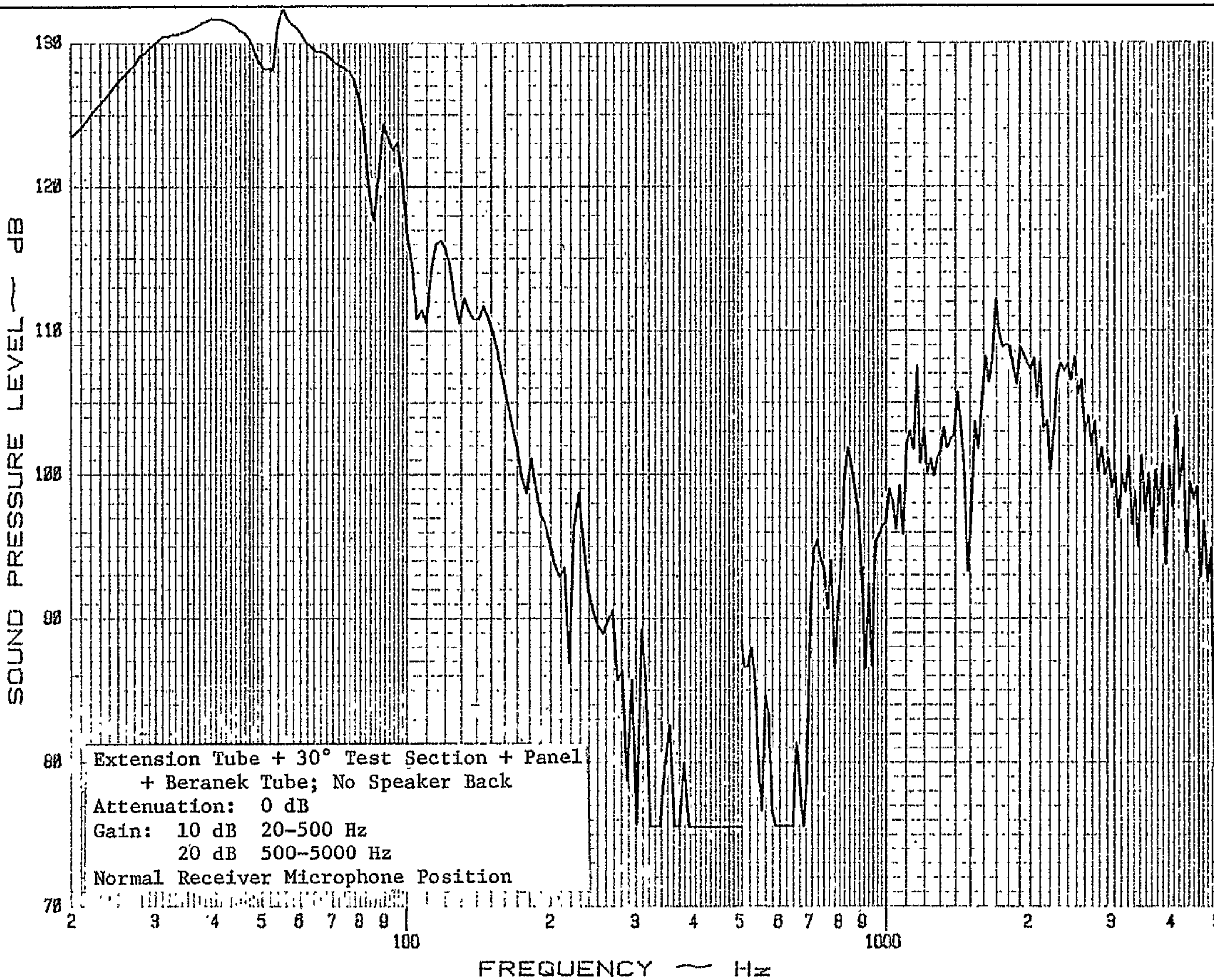

Figure 92: Experimental Sound Pressure Level for the Normal Receiver Microphone Position and with a Test Panel Installed.

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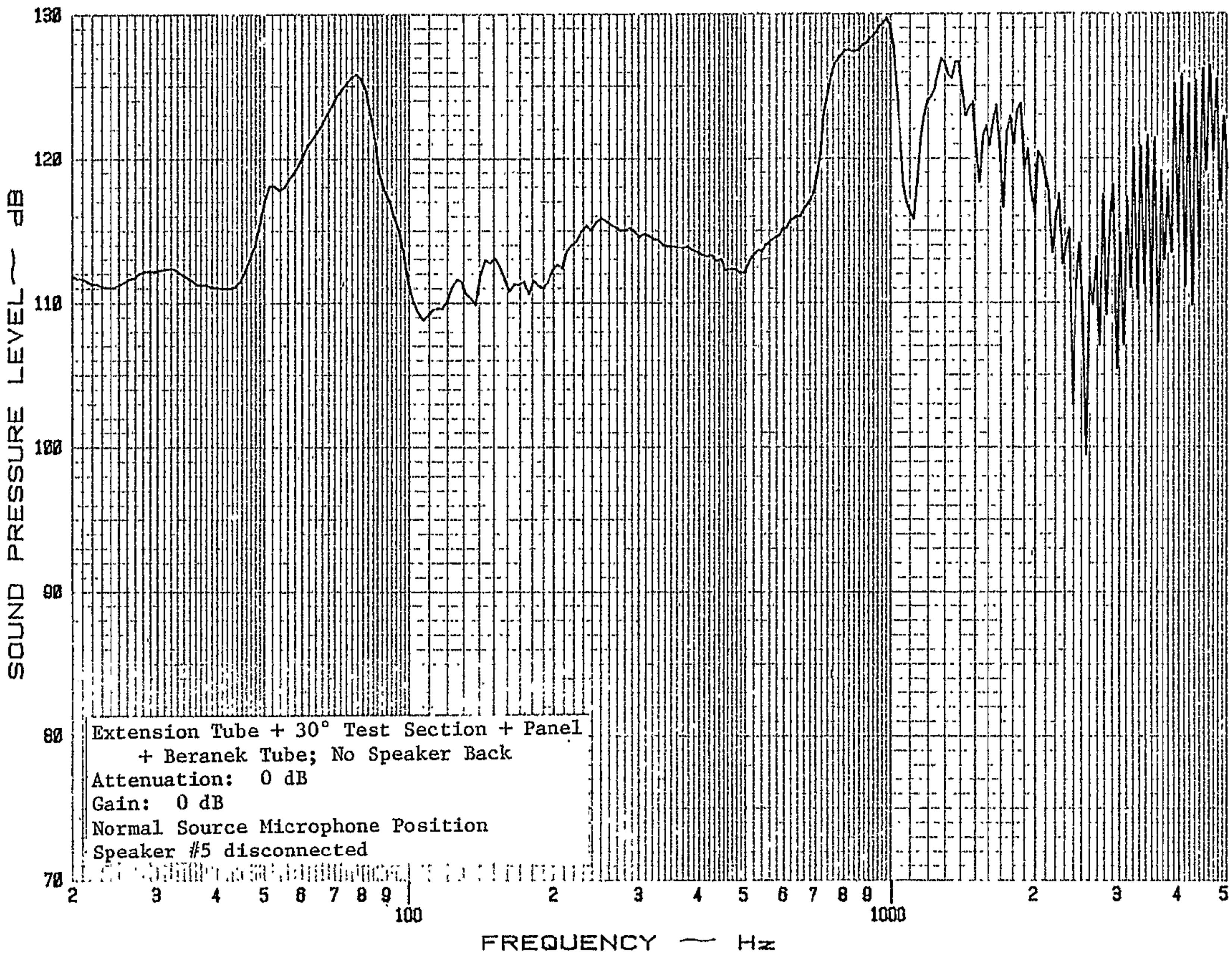

Figure 93: Experimental Sound Pressure Level for the Normal Source Microphone Position, a Test Panel Installed and Speaker #5 Disconnected.

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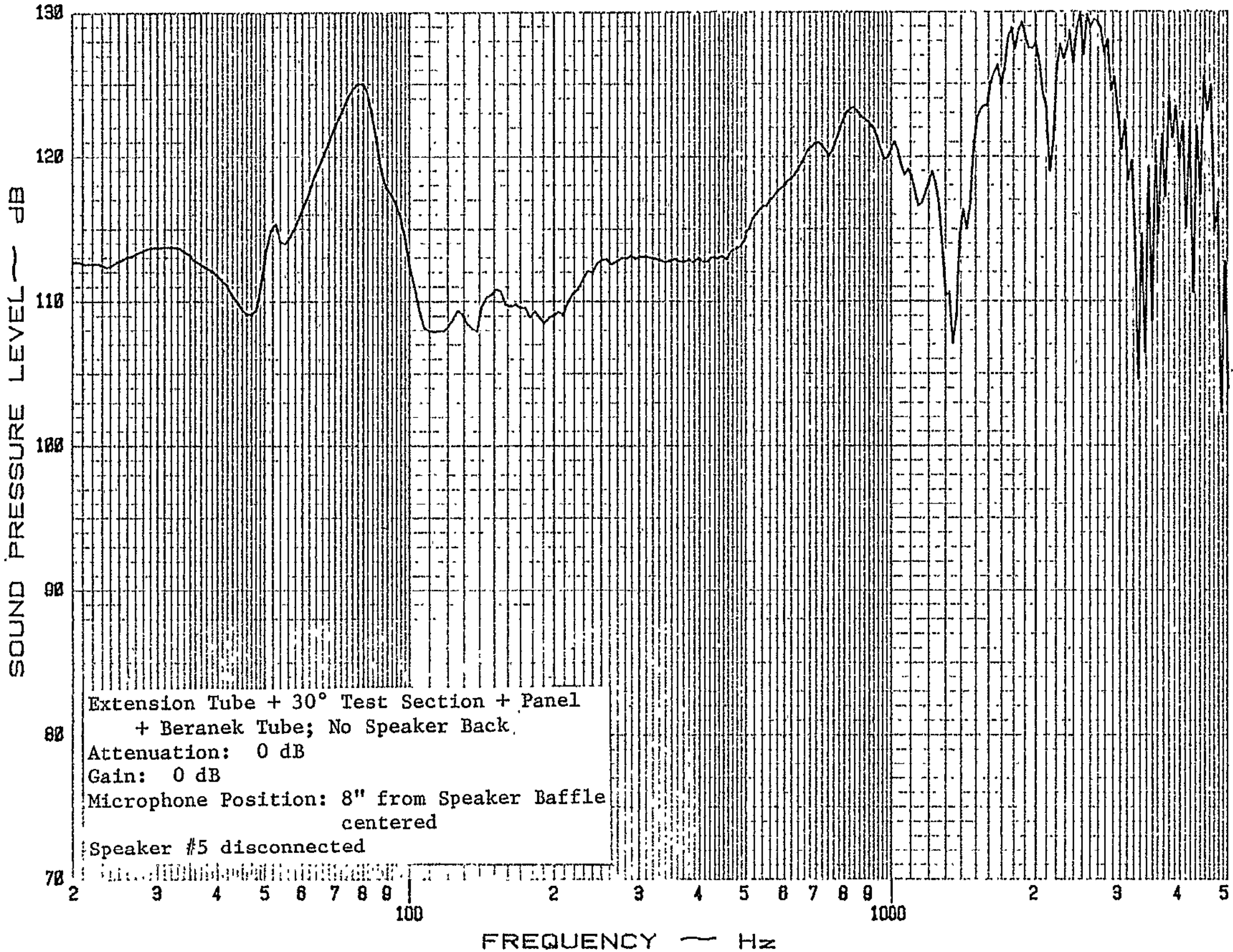

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Figure 94: Experimental Sound Pressure Level for a Microphone Position at a Distance of 8" from the Speaker Baffle, a Test Panel Installed and Speaker #5 Disconnected.

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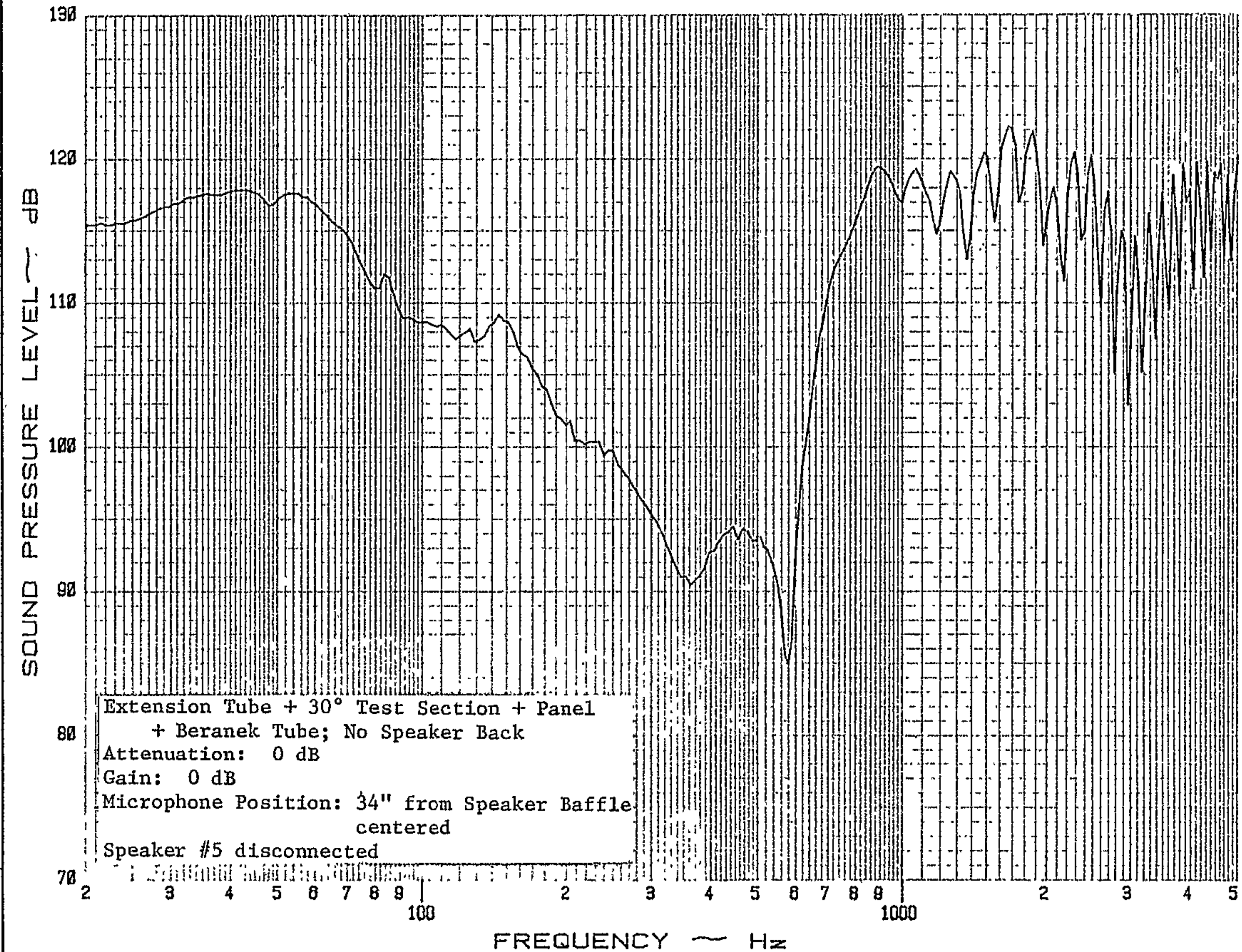

Figure 95: Experimental Sound Pressure Level for a Microphone Position at a Distance of 34" from the Speaker Baffle, a Test Panel Installed and Speaker #5 Disconnected.

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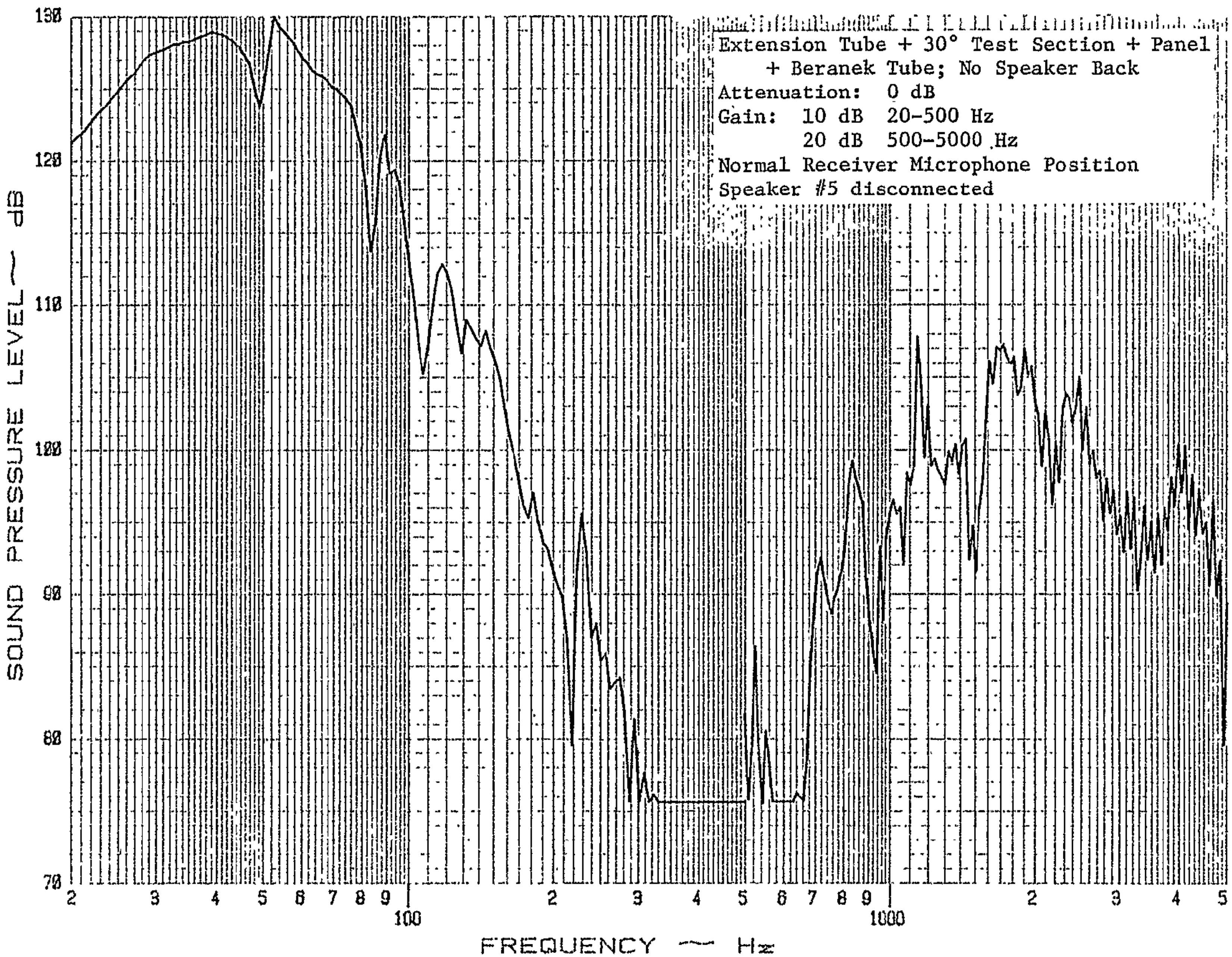

Figure 96: Experimental Sound Pressure Level for the Normal Receiver Microphone Position, a Test Panel Installed and Speaker #5 Disconnected.

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